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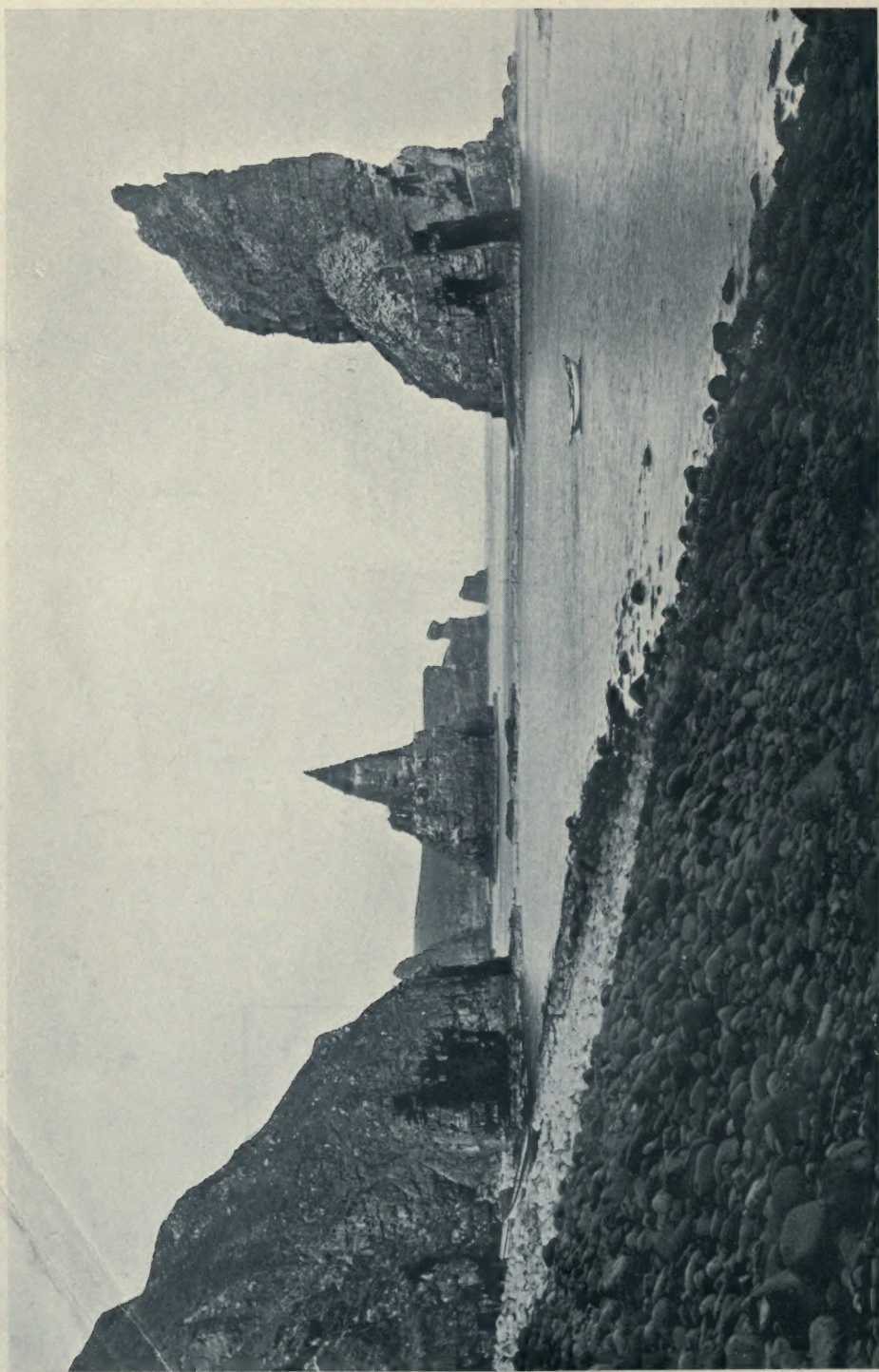
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THE STACKS OF DUNCANSBY; John o' Groat's Sandstone.

110 AND 116
MEMOIRS OF THE GEOLOGICAL SURVEY,
SCOTLAND.

THE GEOLOGY OF CAITHNESS.

(SHEETS 110 AND 116, WITH PARTS OF 109,
115 AND 117.)

BY

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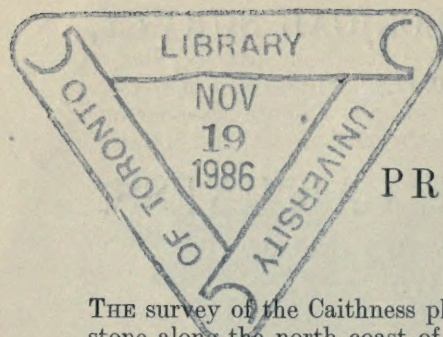


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PREFACE.

THE survey of the Caithness plain and the outliers of Old Red Sandstone along the north coast of Sutherland has been in progress for a number of years. Most of the ground is low-lying and there is little deer forest; consequently it was suitable for work in the latter part of autumn when the deer-forest ground was no longer open. In 1886 Dr. Horne and Dr. Peach began the examination of the Old Red Sandstone near Tongue, and since then the mapping has been carried on at intervals, during the limited time available each year.

Dr. Horne and Dr. Peach mapped most of the outliers in the north of Sutherland. Dr. Horne also investigated the area about Westerdale, Scotscladder and Reay. Mr. Greenly mapped part of Sutherlandshire and of the north coast of Caithness about Castletown. Mr. Pocock was engaged in the neighbourhood of Halkirk and Loch Calder, and surveyed also the upper portion of the basin of the Berriedale Water and of Strathmore. Dr. Peach, who had general charge of the work in Caithness till September 1905, surveyed the ground about Loch Watten, Georgemas, Loch Shurrery, Brough and Dunnet Head. Dr. Crampton has probably mapped a larger part of Caithness than any other member of the Geological Survey, including the north-east of the county from Wick by Duncansby to Ham, the Berriedale and Braemore districts, and the Sarclet Anticline as far south as Lybster. Mr. Carruthers mapped most of the Latheron Syncline, including the coast from near Dunbeath to Lybster, and carried the work northwards through the moorland to near Loch Watten. Mr. Anderson surveyed a small area near Latheron. After 1906 Mr. Hinxman was District Geologist in charge of the field-work.

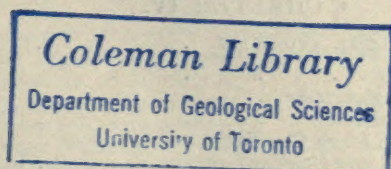
Since the services of many of those who originally surveyed the ground were no longer available, when the Memoir was written, some re-examination of their areas became necessary. Accordingly Dr. Crampton visited and examined the area between Dunnet and Thurso, and Mr. Carruthers re-examined the district between Achanarras and Thurso and thence westwards by the coast to Reay. Dr. Peach and Dr. Horne have prepared a chapter on the glaciation of the whole county, besides describing the solid geology of the areas which they mapped.

The fossil fishes collected were in all cases submitted to Dr. Traquair for identification, and the fossil plants to Dr. Kidston. Mr. D. Tait has compiled the bibliography, and has also furnished valuable information about the Leavad boulder. The photographs were taken by Mr. Lunn. Dr. Flett has contributed an introductory chapter and also an account of the petrography of the igneous rocks. Dr. Kitchin and Dr. Lee have named the Secondary and Tertiary fossils.

Much help has been received in course of the survey from gentlemen resident in the county. Provost Durran of Thurso, Bailie Simpson of Wick, Mr. Nicolson of Nybster, Mr. Sutherland of Gersa, Mr. Charles Johnston of Wick, Mr. King and Mr. William Macpherson of Langwell are among those to whom the authors of this Memoir desire to tender their thanks.

A. STRAHAN,
Director.

Geological Survey Office,
28 Jermyn Street, London,
6th January 1914.



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THE GEOLOGY OF CAITHNESS.

CHAPTER I.

INTRODUCTORY.

THE area described in this memoir is almost co-extensive with the county of Caithness. It includes the whole district represented on Sheets 110 and 116 * of the one-inch map of the Geological Survey of Scotland, but some account is also given of parts of Caithness and Sutherlandshire to the west of those Sheets and included in Sheets 115 and 109. Of these, Sheet 115 was published in 1898, but Sheet 109 will not be issued for a year or two. The northern part of Dunnet Head, which enters into Sheet 117, is also briefly referred to, but only part of this map has yet been surveyed. Our object in thus transgressing the boundaries of the one-inch maps is to give a general account of the Old Red Sandstone of Caithness and of its relations to the older rocks on which it rests: but the crystalline schists and gneisses receive special description only where they fall within the boundaries of the county. The scattered outliers of Old Red in the north of Sutherland, as far west as Tongue, are included in the scope of this memoir.

Caithness may best be regarded as a great plain more or less dissected by stream-courses, and in the flatness of its contours no less than in the nature of its rocks it differs greatly from Highland counties such as Ross and Inverness. Its characteristic rock-formation is the Middle or Orcadian Old Red Sandstone, which in the south and west of the county consists largely of breccias, conglomerates, red mudstones and arkoses, whereas in the north and east the typical grey Caithness flagstones underlie wide expanses. The Old Red Sandstone rests on an irregular platform of much older rocks, principally granites, gneisses, mica-schists and quartzites such as form a large part of east and central Sutherlandshire. At the time when the Old Red Sandstone was deposited, these were practically in the same condition as they are in now. It is clear that formerly the Old Red extended far to the west of its present limits, and the scattered outliers of conglomerate that occur in Ben Griam, to the south of Ben Armine, and at Strathy and Kirkatomy on the north coast, are the remnants of an extensive deposit that has in large part been

* Sheets 110 and 116 are colour-printed maps, published at 2s. 6d. each. Sheet 115 is published hand-coloured, and costs 19s. 3d. Sheet 109 is not yet published, but is in preparation.

stripped by denudation off the surface of the Highland schists and gneisses.

The general structure of Caithness is exceedingly simple. It forms part of a great basin which extends north beyond the Orkneys. The lowest beds occur in the south and west of Caithness, while the highest beds are found at John o' Groat's, and are still better represented in the Orkney Islands. It would not be right to infer, however, that as we travel northwards through Caithness we are constantly passing over higher and higher strata, for the rocks have been bent into a great arch or dome whose axis emerges at the coast near Sarclet, about six miles south of Wick. This brings up the conglomerates which belong to the base of the series. On each side of this arch the strata lie in great troughs, the one to the south forming the Latheron Syncline, while on the north there is a well-marked Ackergill Syncline, the axis of which runs in a south-west direction to the west of Wick.

Another important feature in the structure of Caithness is the Brough fault. First seen on the coast to the east of Dunnet Head, this great fracture passes inland to the west of Loch Watten, but seems to divide into two branches near the Loch of Toftingall. One branch passes south-south-west and is lost beneath the moors near Loch Rangag, while the other runs south-east and finally south to reach the neighbourhood of Lybster. To the west of this fault, around Westerdale, Halkirk and Thurso, the rocks as a whole have dips to the north and north-east.

Other important faults are the one which at Janetstown lets down a narrow strip of rocks along the coast in the centre of the Latheron Syncline, and the group of faults which dislocate the strata at Gills Bay, John o' Groat's and Duncansby.

In the extreme south of Caithness there is a considerable outlier of Old Red Sandstone in the Berriedale district. The rocks have been subdivided into the following groups:—

4. Berriedale Sandstones and Flags.
3. Badbea Breccia.
2. Ousdale Mudstones.
1. Ousdale Arkoses and Langwell Conglomerates.

They have a total thickness of about 3000 ft. and belong probably to the lowest part of the Caithness Old Red Sandstone.

In the Dunbeath district there is at the base of the succession a group of flags, sandstones and conglomerates which are believed to correspond with the three highest of the groups above named. These are followed by sandstones, blue and grey flags, and some limestones, which sweep round the Latheron Syncline, and probably belong to the Helman Head Beds or part of the Wick Flagstone Group.

The lowest rocks seen on the axis of the anticline at Sarclet are the Sarclet Conglomerates. Above these comes a group of mudstones about 800 ft. thick which are correlated with the mudstones of Braemore and Ousdale. The Sarclet Conglomerate, accordingly, must be approximately on the same horizon as the conglomerates that form the base of the series at Langwell and Braemore. From Sarclet it is possible to trace a nearly unbroken succession northwards along the

coast to the John o' Groat's Beds, at Duncansby, and the sequence is as follows :—

	John o' Groat's Sandstone	..	..	(Ft.)
Thurso	Mey Beds ..	..	..	2000
Flagstone	Thurso Flagstones ..	..	..	5000
Group.	Ackergill Beds ..	..	..	

(POSITION OF ACHANARRAS AND NIANDT BEDS).

Passage	Noss Beds ..	..	..	250
Bed	Castle Sinclair Flags ..	..	..	400
Group.	Field Beds ..	..	..	700
	Papigoe Beds ..	..	..	1000
	Wick Beds ..	..	..	2500
Wick	Red Beds ..	..	..	1000
Flagstone	Helman Head Beds ..	..	..	1500
Group.	Ellens Goe Conglomerate ..	..	..	50
	Ulbster Sandstone ..	..	..	300
Barren	Mudstones ..	..	..	800
Group.	Sarclet Sandstone ..	..	..	300
	Sarclet Conglomerate ..	..	..	200

Several features of this succession are of a remarkable character. The first of these is the enormous thickness of the Caithness Old Red Sandstone which is probably 16,000 to 18,000 ft. This was pointed out in 1878 by Sir Archibald Geikie, and the detailed work of the Geological Survey has amply confirmed his conclusions. Again, in the whole of this vast pile of sediment there is no distinct unconformability, though there is some evidence to suggest the presence of one at the base of the John o' Groat's Sandstone and another above the Ousdale and Sarclet Mudstones. The coarser fragmental rocks, conglomerates, breccias and arkoses are found at the base and are often of a red colour, while the upper part of the succession (with the exception of the highest John o' Groat's Beds) consists essentially of flagstones, fine-grained, grey in colour, and remarkably uniform in character. This flagstone series is 11,000 to 12,000 ft. in thickness. No interbedded volcanic rocks have been found in Caithness.

With few exceptions * all geologists who have made careful study of the Caithness Old Red Sandstone admit that this formation was deposited in a large fresh-water lake. This subject is more fully discussed in a later chapter of this memoir (*see* Chap. IX.). Considerable differences of opinion have arisen, however, as to the exact age of the beds and especially as to their relation to the Lower Old Red Sandstone of Central Scotland. Murchison † subdivided the Caithness Old Red Sandstone into three groups :—

3. Upper Red and Yellow Sandstones (including John o' Groat's and Dunnet Head Sandstones).
2. Middle Grey and Dark-coloured Flags.
1. Lower Red Conglomerate and Sandstones.

He considered that the coarse-grained, red strata of the south of Caithness were on the same horizon as the red sandstones and con-

* Macnair, P., and J. Reid, "Palæontological Considerations on the Old Red Sandstone of Scotland," *Geol. Mag.*, 1896, p. 217. "On the Old Red Sandstone of Scotland," *ib.*, p. 106 and p. 570.

† Murchison, Sir R. I., "On the Succession of the Older Rocks in the Northernmost Counties of Scotland," *Quart. Jour. Geol. Soc.*, vol. xv., 1859, p. 394.

glomerates, now known as the Caledonian Old Red, south of the Grampians. These strata in Caithness are very barren, but the richly fossiliferous flagstones were correlated by Murchison with the Middle Devonian, principally on account of the similarity in their fossil remains. In his Upper Old Red two entirely distinct groups of strata were included, for, as Sir Archibald Geikie showed, the Dunnet sandstone being presumably the same as that of Hoy* in Orkney, rests unconformably on the Caithness flags and must be separated from the John o' Groat's Sandstone by a long period of erosion.

Sir Archibald Geikie† arrived at a different conclusion from Murchison. He declined to admit the validity of the evidence for establishing a middle division of the Old Red Sandstone. His argument rested principally on the following points. If Murchison's classification is accepted the Lower Old Red is over 20,000 ft. thick and the Middle Old Red about 18,000 ft., and their conjoint thickness is so great as to make it improbable that they are distinct. The genera and species of fossils in these deposits certainly show considerable differences, but these are less than Murchison believed, and moreover they might be explained as the faunas of two lakes that existed for a long time side by side, but rigidly separated from one another and belonging to different drainage systems. In his opinion the simplest explanation of the facts was to assume that the Caithness Old Red (with that of Orkney and the Moray Firth area) was deposited synchronously with the Caledonian Old Red of Forfarshire, Perthshire, etc., and both belonged to the Lower Old Red Sandstone.

This reasoning, however, did not carry conviction, especially as the differences between the two faunas when they were more carefully studied tended to increase rather than to diminish. Dr. Traquair, whose knowledge of the Old Red fossil fishes was unrivalled, maintained always that they were of such a nature that they could not be explained on this hypothesis. Dr. John Evans‡ in 1891, after reviewing all the evidence regarding the distribution of the fossil fishes of Caithness, concluded that they showed closer affinities to the Upper Old Red Sandstone fauna than to the Lower, and in 1902 Dr. Traquair§ endorsed this opinion. He pointed out that three distinct fish faunas could be recognised in the Old Red Sandstone of Scotland, an Upper, a Middle and a Lower. Of these the last named was mostly closely allied to the Silurian fish-faunas. The fishes of the Upper Old Red of Scotland were unmistakably allied to those of the Upper Devonian, and the fishes of Caithness had marked affinities to those of the Middle and Upper Devonian.

The evidence of the fossil fishes, however, though strong is perhaps not conclusive. The fossil plants on the other hand afford a firm basis of argument. In 1902 Dr. Kidston|| placed on record

* Geikie, [Sir] A., "The Old Man of Hoy," *Geol. Mag.*, 1878, p. 51. "The Old Red Sandstone of Western Europe," *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 345.

† *Loc. cit.*

‡ Evans, J. W., "The Geology of the North-east of Caithness," London, 1891.

§ Traquair, R. H., in "The Geology of Lower Strathspey," *Mem. Geol. Surv.*, 1902, p. 81.

|| Kidston, R., in "The Geology of Lower Strathspey," *Mem. Geol. Surv.*, 1902, p. 83.

the general results of his investigations of the Old Red floras. He recognises three subdivisions. The flora of the Upper Old Red is quite distinct from those of the two underlying groups, each of which, however, is characterised by a flora peculiar to itself. Mr. Macnair * seems to have been the first to direct attention to the differences between the floras of the Caithness Old Red Sandstone and the Lower Old Red Sandstone south of the Grampians. Now it is inconceivable that if two large fresh-water lakes existed side by side, and were separated by only a narrow barrier, the plant remains entombed in the sediment that gathered in these lakes should be totally different. There is no escape from the conclusion that the Old Red Sandstone of Caithness, taken as a whole, belongs to a distinct epoch from that in which the Caledonian Old Red Sandstone south of the Grampians was laid down. We are therefore entitled by the fossil evidence to regard the existence of a Middle Old Red Sandstone in Scotland as definitely proved.

Another problem of some importance is whether the Old Red Sandstone of Caithness can be split up into definite zones, each characterised by a peculiar assemblage of fossil fishes. This possibility was at least suggested by Charles W. Peach's discovery † that among the John o' Groat's Sandstones near Duncansby three beds of dark flags occur containing a fish-fauna of distinctive type. Sir Archibald Geikie ‡ in 1878, with the help of data collected by Charles W. Peach, discussed the vertical range of the fishes in the Caithness flagstones and arrived at no very positive conclusions. He was aware, however, that *Osteolepis microlepidotus* and *Coccosteus pusillus* (*C. minor*) were restricted to horizons near the top of the flagstones. The time was not ripe for an adequate treatment of the subject because much work had yet to be done before the palæontological determination of the fossils could be regarded as satisfactory.

It is not too much to say that during the whole of his work on the Old Red fishes Dr. Traquair constantly kept this problem in mind. He was not satisfied with investigating the structure, affinities and classification of the fossils, but aimed also at establishing their value to the geologist as a means of discriminating the horizons at which they occur. In 1896 he announced § that he was able to recognise three distinct faunas in the Caithness Old Red, one characterising the John o' Groat's Beds, another in the Achanarras quarry, and a third in the rocks that form the district between Halkirk and Thurso.

The list of fossils is given below :—

JOHN O' GROAT'S BEDS.

Microbrachius Dicki (*C. W. Peach*).

Dipterus macropterus, *Traq.*

Tristichopterus alatus, *Egert.*

* Reid, J. W. Graham, and P. Macnair, "*Parka decipiens*, its Origin, Affinities, and Distribution," *Trans. Geol. Soc. Glasgow*, vol. xi., 1897, p. 110.

† Peach, C. W., "On Fossil Fish, new to the Old Red Sandstone of Caithness," *Rep. Brit. Ass.* (Aberdeen Meeting), 1860, p. 120.

‡ *Loc. cit.*

§ Traquair, R. H., "Achanarras Revisited," *Proc. Roy. Phys. Soc. Edin.*, vol. xii., 1894, p. 279.

ACHANARRAS QUARRY.

Palæospondylus Gunni, *Traq.*
Diplacanthus striatus, *Ag.*
Rhadinacanthus longispinus (*Ag.*).
Mesacanthus sp.
Cheiracanthus Murchisoni, *Ag.*
Pterichthys Milleri, *Ag.*
 „ *productus*, *Ag.*
 „ *oblongus*, *Ag.*
Coccosteus decipiens, *Ag.*
Homosteus Milleri, *Traq.*
Dipterus Valenciennesii, *Sedgw. and Murch.*
Glyptolepis paucidens (*Ag.*).
Diplopterus Agassizii, *Traill.*
Osteolepis macrolepidotus, *Ag.*
Cheirolepis Trailli, *Ag.*

THURSO AND HALKIRK DISTRICT.

Homacanthus borealis, *Traq.*
Rhadinacanthus longispinus (*Ag.*).
Mesacanthus Peachi (*Egert.*).
Cheiracanthus sp. (perhaps two species).
Coccosteus decipiens, *Ag.*
 „ *minor*, *H. Miller.*
Homosteus Milleri, *Traq.*
Dipterus Valenciennesii, *Sedgw. and Murch.*
Glyptolepis paucidens (*Ag.*).
Thursius macrolepidotus (*Sedgw. and Murch.*).
Thursius pholidotus, *Traq.*
Osteolepis microlepidotus, *Pander.*
 Scales doubtfully resembling those of *Gyroptychius*.

The Achanarras fauna was easily seen to be the same as that of the Old Red of Stromness in Orkney, Cromarty, and the shores of the Moray Firth (Gamrie, Lethen, Tynet, etc.), but as yet the other two faunas were not known outside of Caithness. In 1896, however, Dr. Flett* found the John o' Groat's fauna in Orkney in rocks long believed to correspond stratigraphically to the John o' Groat's Beds of Caithness. Subsequently † he was able to prove that strata containing the Thurso fauna covered a wide area in the Orkneys, and the three lists of fishes obtained in the corresponding beds in the two counties were very similar. Of the three faunas that of Achanarras occurred at the lowest horizon in Orkney. In 1900 Dr. Peach also proved that the fish beds of Achanarras lie below those of Halkirk and Thurso.

Meanwhile, working in Westerdale to the south of Achanarras, Dr. Horne had mapped a series of dark flags underlying those of Achanarras quarry. Some of these beds are highly fossiliferous, but the only fish they contain is *Thursius macrolepidotus*. Now this fish occurs in the Thurso flagstones but not at Achanarras. As yet all attempts to find the Achanarras fauna on the east coast of Caithness had failed, but in 1908 Mr. Carruthers ‡ proved its occurrence in beds of thin slaty calcareous flagstone at Niantd on the north side of the

* Flett, J. S., "On the Discovery in Orkney of the John o' Groat's Horizon of the Old Red Sandstone," *Proc. Roy. Phys. Soc. Edin.*, vol. xiii., 1896, p. 255.

† Flett, J. S., "The Old Red Sandstone of the Orkneys," *Trans. Roy. Soc. Edin.*, vol. xxxix., 1898, p. 383.

‡ Carruthers, R. G., "On the Stratigraphical Position of the Achanarras Fauna in the Old Red Sandstone of Caithness," *Summary of Progress for 1908, Mem. Geol. Surv.* 1909, p. 87.

Latheron Syncline. The rocks above it are lithologically of the "Thurso type," but the Niandt bed is placed above the coarse flagstones of the "Wick type" and about 10,400 ft. above the Sarclet conglomerates. These rocks are faulted down by a great dislocation which runs in a north-east direction, and is estimated by Mr. Carruthers to have a throw of over 6000 ft. On this hypothesis the "Niandt Bed" should outcrop on the coast line somewhere between Ackergill and Noss Head, but it has not been found there and is apparently faulted out by one of the numerous dislocations that occur in that part of the coast.

Mr. Carruthers* has proposed to subdivide the Middle Old Red of Caithness into the following lithological and palæontological groups:—

3. John o' Groat's Sandstone.
2. Caithness Flagstones { 2b. Upper or *Coccosteus* Group.
2a. Lower or *Thursius* Group.
1. Red Rocks of Berriedale, etc. (unfossiliferous).

Of these groups, the lowest comprises the basement breccias, conglomerates, arkoses, and mudstones, mostly red in colour, and so far as is yet known, unfossiliferous. The Caithness Flagstones include all the strata from the base of the Helman Head Beds to the base of the John o' Groat's Beds. They fall into three subdivisions according to their lithological characters.

The Thurso Flagstone Group.

The Passage Bed Group.

The Wick Flagstone Group.

The Wick flagstone group includes the Wick Flags, Red Beds and Helman Head Beds, and as these contain principally *Thursius macrolepidotus* with *Dipterus Valenciennesii*, they are defined palæontologically as the *Thursius* Group (2a). The Passage Beds and Thurso Flagstone Group contain a much richer fauna of which *Coccosteus decipiens* is a conspicuous member, and they are defined palæontologically as the *Coccosteus* Group (2b). The Achanarras band (Niandt Bed) lies at the junction between the Passage Beds and the Thurso Flagstone Group.

It should be noted, however, that *Thursius macrolepidotus* is not confined to the "*Thursius* Beds," but occurs also in the Passage Beds and the Thurso Flagstone Group. On the other hand, and this is a remarkable fact, it has never yet been found in the richly fossiliferous Achanarras band, or in any of the districts where the Achanarras fauna occurs.

The vertical distribution of the fossil fishes of the Caithness flags is an interesting subject, but it could not be satisfactorily attacked till the county had been carefully mapped and the stratigraphical position of the different beds established. To this subject Dr. Traquair had devoted a large amount of study, and it was hoped that he would contribute a discussion of the results to this memoir. He died, however, before this work was completed, and as no one but an expert ichthyologist, familiar with the collections of Caithness fishes scattered through the museums of Europe, could undertake such a work we must for the present defer consideration of it.

* *Loc. cit.*

HISTORY OF INVESTIGATION.

It was well known about the beginning of the nineteenth century that Caithness consisted largely of grey flagstones, and that in the north of the county there were extensive tracts of sandstone, while great masses of conglomerate were a conspicuous feature of the districts about Berriedale and Reay. We find, for example, that Jameson (1800) * in his brief tour had noted all the principal features of the lithology. By 1820 when Ami Boué's account of the geology of Scotland was published these beds were regarded as part of the Old Red Sandstone formation, principally no doubt because of the prevalence of conglomerate and red sandstone at the base of the series. His account of Caithness is founded on the descriptions already published by Jameson. About this time the export of Caithness flags commenced.

An important event in the study of Caithness geology was Murchison's first tour in the summer of 1826, of which the results appeared in his paper on "The Coalfield of Brora in Sutherlandshire, etc." This was followed by a second tour in 1827 in which he was accompanied by Sedgwick. Their observations were embodied in a paper which was read to the Geological Society of London in May and June 1828. For the first time the stratigraphy of Caithness was now established on a firm basis of observation and reasoning. They recognised that in Caithness there was a generally ascending sequence from the conglomerates of the Ord to the sandstones of John o' Groat's. Figures and descriptions (by Valenciennes and Pentland) of some of the fossil fishes are given. Some of them were sent to Cuvier (1827) who recognised their nature, placing them in the same group as the "bony pike" *Lepidosteus*. With others, however, he was entirely at fault, as he regarded the bony plates as belonging to a turtle (*Trionyx*). They really belonged to *Coccosteus*. While the rocks are grouped under the Old Red Sandstone and correlated with the sandstones of the hills behind Brora, Foyers, Cullen and Elgin, they are supposed to be contemporary with the Carboniferous, but of course at that time the Devonian System had not yet been established. It was suggested that the fossils indicated a fresh-water origin for the deposits. The sandstone of Dunnet Head was described as the "upper red sandstone," and was tentatively correlated with the red sandstones of Arran.

In 1834 Agassiz visited Scotland and specimens of fossil fishes from Caithness were shown to him. They proved to be of great interest, being mostly new species, and a great stimulus was given to the investigation of the Old Red Sandstone of Scotland. Hay Cunningham's account of Sutherland appeared in 1841, and the same year was rendered notable by the publication of Hugh Miller's "Old Red Sandstone." Robert Dick had already been examining the rocks in the neighbourhood of Thurso, and he was able to confirm many of Hugh Miller's statements. Very soon these two geologists got into correspondence, and Dick began to send specimens of fossils to Miller for study. About the same time Malcolmson was investigating the Old Red Sandstone of the Moray Firth area, though the publication of his results was accidentally delayed till 1859. Now followed a period of extraordinary activity in the study of the Old Red

* For titles of papers, books, etc., see the Appendix (p. 180) under the dates given.

Sandstone of the North of Scotland. Fossil fishes were being sent by many collectors to Agassiz, who was preparing his volume on the *Poissons Fossiles du Vieux Grès Rouge* (1844-45). In 1849 Hugh Miller's *Footprints of the Creator* was published, and contained descriptions of many of Robert Dick's remarkable discoveries. In 1853 Charles W. Peach came to reside at Wick, and brought to bear on Caithness geology the resources of a highly-trained and vigorous intellect, already skilled in the discrimination of obscure fossil remains. Meanwhile, John Miller of Scrabster, Cleghorn and others were advancing our knowledge both of the solid rocks and of the drifts that overlie them. After Hugh Miller's death in 1856, Robert Dick went on working, but as he never published his discoveries there was no immediate gain to science. The beautiful specimens which he collected, however, ultimately passed into the custody of the Royal Scottish Museum, where they furnished material for some of Traquair's most important papers.

In 1857 Murchison again came to Caithness, and, accompanied by C. W. Peach, visited Dick in Thurso where the well-known scene was enacted, Dick making a model of the geology of Caithness by means of flour on a board in his bakehouse. The results of Murchison's tour were communicated to the Geological Society of London and published in 1858. The time he had spent in Caithness was short, and much of the value of his paper is due to the information he had gleaned from Peach and Dick. This paper marks a great advance in the knowledge of Caithness geology, and was, for twenty years, to be the principal source of information on the subject. For the first time the Sarclet Anticline, the central feature of the structure of the east part of the county, was described, and the uprise of the old floor of crystalline rocks through the flagstones at Dirlot. Murchison correlated the red sandstones and conglomerates with the Caledonian Old Red Sandstone; the Caithness flagstones he regarded as a Middle Old Red Sandstone, and he considered the Upper Old Red Sandstone of Dunnet to be conformable with the flagstones beneath them. Of these conclusions only the second is now regarded as valid. Descriptions of the fossil plants and the *Estheria* of the Caithness flags were provided by Salter and by Rupert Jones. In 1858 C. W. Peach announced the discovery of a band yielding new fossil fishes at John o' Groat's, and in 1861 some of them were described and figured by Sir Philip de M. Grey Egerton.

About this time interest was awakened in the boulder-clay of the east of Caithness by the discovery in it of shells, sometimes whole but mostly in fragments, and Dick, Peach and Cleghorn investigated it carefully and published brief papers on the subject. But as a sketch of the history of research on the glacial phenomena has been contributed to this memoir by Dr. Horne, we shall refer the reader to it for information (see p. 118). In 1866 Robert Dick died; and Peach left Wick to settle in Edinburgh in 1865.

By far the best and most complete account of the geology of Caithness which has appeared up to the present time is that contained in Sir Archibald Geikie's paper "On the Old Red Sandstone of Western Europe" (1878). His knowledge of the coast sections was very complete, and was obtained by a series of careful traverses in which he was accompanied by Dr. B. N. Peach, and at a later date by Dr. Horne, but the structure of the county inland, buried as so

much of it is beneath peat and boulder-clay, was not so fully ascertained. Particulars respecting the distribution of fossils in Caithness were supplied by the veteran C. W. Peach. The principal features of the paper, however, are the skill with which all the information previously published, and a large amount of new observations, were woven into a consistent whole, and the literary grace with which the subject was handled.

Sir Archibald Geikie's work has in very large measure stood the test of time and proved a sound foundation for further research. Thus he recognised the unconformity which exists between the Upper Old Red Sandstone of Hoy and the flagstones, and the wide gap which must consequently separate the Dunnet Head Sandstone and the Caithness Flagstones. Accepting the old threefold classification into John o' Groat's sandstones, flagstones, and lower red beds and conglomerate, he further subdivided the sequence into a number of groups to which he gave names from the typical localities at which they occur, principally on the east coast. These are as follows (in descending order):—

John o' Groat's Sandstone.
Huna Flagstones.
Gill's Bay Sandstone
Thurso Flagstones.
Wick Flagstones.
Berriedale Sandstones
Badbea Breccia.
Braemore Sandstones.
Basement Conglomerate

A comparison of this succession with that given on p. 3 will show that most of these subdivisions are accepted in this memoir. He also recognised the existence of a passage group between the Wick and Thurso Flagstones. Most of the essential features of the structure of Caithness were described in this paper, *e.g.* the Sarclet Anticline, Wick and Latheron Synclines, and the Brough fault. The great overlap by which members high in the flagstone group come to rest on the crystalline schists and gneisses in the district of Reay was clearly demonstrated, and the very uneven nature of the floor on which the Old Red Sandstone was laid down fully described. Sir Archibald Geikie also discovered the volcanic neck at Duncansby, and he gives interesting particulars regarding its rocks and the crystalline minerals in the tuff. The correlation of the beds on the east and west sides of the Brough fault was on the whole successfully achieved. The enormous thickness of the Caithness flags impressed Sir Archibald Geikie very strongly, and his estimate of 16,200 ft. must be very near the truth. In his paper also he brought forward the suggestion that the Middle Old Red Sandstone at Cromarty and in the Moray Firth does not represent the base of the Caithness series but corresponds to beds at a much higher level. Mr. Carruthers's discovery that the Niandt "limestone," which contains the same fauna, is far above the Sarclet conglomerates, entirely supports this conclusion.

He differed from Murchison, as has already been stated, in holding that there was no evidence to justify the relegation of the Old Red Sandstone of Caithness to a distinct division of the system from the Caledonian Old Red, and in this subsequent investigators have reverted to Murchison's views; but this paper provides a very

judicious and wonderfully graphic account of all the essential features of Caithness geology.

Dr. Traquair's work in Caithness began in 1875 with the publication of papers on *Cheirolepis* and on *Tristichopterus alatus*. It continued for nearly forty years, and, after Dr. Peach and Dr. Horne had in 1881 finally solved the problem of the origin of the shelly boulder-clay, the centre of interest in Caithness geology shifted once more to the domain of palæontology.

With brilliant success Dr. Traquair continued to investigate the fish-fauna of the Middle Old Red Sandstone, and by frequent visits to Caithness he kept in touch with the local collectors. Men like John Gunn, J. Reid, W. Boyd Kinnear, and D. Calder, placed their specimens at his disposal, and everything of interest that was discovered in the quarries sooner or later passed through his hands. Though by no means a rapid worker, he exhibited an extraordinary combination of enthusiasm, caution, and sagacity, and he very rarely made a mistake. In course of time the whole of the palæichthyology of the Old Red Sandstone was revised by him and placed on a firm basis. Among his most important contributions to our knowledge of the fossil fishes of Caithness, is his paper "On the Nomenclature of the Fossil Fishes of the Old Red Sandstone of Great Britain" (1888), which cleared up a great number of doubtful points as regards the distinctions between the more obscure species. It was the result of many years of work, not only on the specimens in the Royal Scottish Museum, but also on collections in private hands and in other museums. Gradually he built up the unrivalled series of Old Red fossil fishes under his charge in Edinburgh, having acquired for it the collections of Hugh Miller, Robert Dick, John Miller of Scrabster, and Charles W. Peach. The whole of the fossil fishes obtained by the Survey during its work in Caithness were submitted to him for identification.

One of the fossil fishes which Dr. Traquair described is the remarkable *Palæospondylus Gunni* which has awakened much interest and is still the subject of controversy. It was first obtained at Achanarras, and Dr. Traquair's work on the fossils associated with it in that quarry enabled him for the first time to announce the occurrence in Caithness of the fauna that characterises the Middle Old Red of Stromness, Cromarty, and the Moray Firth basin (p. 6). Among other Caithness fishes whose anatomy and affinities were elucidated by Dr. Traquair's researches, we may mention *Homosteus* (the *Asterolepis* of Hugh Miller), *Microbrachius*, *Thursius*, and *Dipterus macropterus*.

The more notable additions to our knowledge of the geology of Caithness of recent years include Dr. Peach's discovery of volcanic necks on Dunnet Head, Mr. Carruthers's recognition of the Achanarras band at Niantd, and Mr. Tait's description of the transported mass of Cretaceous sandstone in the sand-pit at Leavad.

J. S. F.

CHAPTER II.

THE CRYSTALLINE SCHISTS, GNEISSES AND GRANITES.

THE Old Red Sandstone occupies nearly the whole of Caithness, but the crystalline schists and granites, which have so wide a distribution in Sutherland, form an irregular strip along the boundary of the county between Berriedale and Reay.

The quartzites, quartzose schists and mica-schists, which are here described, were originally sediments, but have undergone profound regional metamorphism, and have also been widely injected by igneous rocks. These sandstones and shales were buried deeply in the earth's crust, and locally invaded by molten igneous masses. Then followed a period of intense plication when the sediments were metamorphosed into schists and the igneous masses altered into gneisses. At a later date more extensive flooding with igneous material occurred. Before the deposition of the Old Red Sandstone, prolonged erosion had cut deeply into the crystalline schists and igneous rocks. Large fragments of these rocks form the conglomerates and breccias, and of their finer debris a great part of the sandstones and flagstones of the Old Red Sandstone is built up. The floor of metamorphic and igneous rocks, on which the Old Red Sandstone rests, is exceedingly uneven, and appears as inliers at considerable distances within the main boundaries of the formation. The elevations upon this floor were gradually overlapped and buried by successive strata.

At a later epoch, denudation again laid bare these elevations as inliers of the metamorphic rocks at Dirlot Castle and Strathmore, on the Thurso River, at Caplaich Hill, west of Dunbeath, and even as far north as Stromness in the Orkney Islands. There is also reason for believing that the schists are not far beneath the surface at Sarclet on the east coast, and at Houstry near Watten, where the rocks are locally of a conglomeratic nature. To the original uneven character of the floor is chiefly due the irregularity of the boundary line between the Old Red Sandstone and the crystalline rocks. The increasing overlap of the Old Red Sandstone, as one passes northward from Berriedale to Reay, arises from the same cause. The extent to which this overlap is exposed by denudation is, on the other hand, governed by the direction of tilting of the rocks which have been subjected to planation.

The Ord granite forms the magnificent headland of the Ord, on the southern confines of the county, and, along the east coast, extends as far north as the mouth of the Ousdale Burn. The granite stretches fully ten miles to the south-west into Sutherlandshire. Along the county march inland, it underlies five miles of peat-covered hills to Blàr a' Ghille Dhomhnaich, but is well exposed in the many branches

of the Allt Staoine, in the Ousdale Burn, on the north and south slopes of Braigh na h-Eaglaise, and at several points on the Langwell Water between Cnoc Allt na Beithe and The Shin, a rocky spur of Cnoc Bad Asgaraidh overlooking the river. Within the county, the northern boundary of this granite forms an approximately east and west line from Blàr a' Ghille Dhomhnaich to the coast at Badsallach (Lower Newport), one mile north of the mouth of the Berriedale Water.

Bounding the Ord granite on its northern margin is a broad belt of crystalline schists, which crosses the Langwell forest with a general east and west strike. Schists occur along the watershed as far north as the Knockfin Heights, a distance of eight miles. Beyond this, another granite mass, the Strath Halladale granite, continuously underlies the peat along the county march for fifteen miles to Beinn Ràtha near Reay. East of the watershed, throughout the peat-covered plateau drained by the head waters of the Berriedale, Glutt, and Dunbeath Waters, the granite forms an intricate complex with the schists. The granite extends, on an average, more than three miles over the march into Caithness, and has a still wider distribution in Sutherland. It forms most of the region in which these rivers take their rise, and stretches nearly as far east as Achnaclyth on the Dunbeath Water. The Old Red Sandstone rests upon it with a very irregular boundary between Braemore and Glutt Lodge. From that point northwards, for twelve miles to Loch Scye, a belt of schists, with a prevalent north and south strike, bounds the granite on its eastern side. The conglomerates of the Old Red Sandstone rest upon these schists, but north of Loch Scye the Old Red Sandstone passes farther west, and again lies upon the granite as far north as Creag Leathan, near Reay.

Near Beinn Ràtha, the schists which bound the granite mass on its western side, with a change in strike from north to north-east, cross the county march from Sutherland into Caithness. They form a northern limit to the granite mass, from Beinn Ràtha as far as Creag Leathan, the junction between the rocks following the change of strike in the schists. These schists form a belt, less than one mile in width, which in a north-easterly direction passes beneath the Old Red Sandstone. The belt of schists is, in turn, followed on its north-west margin by a mass of diorite which forms the grass-covered hillocky ground near Reay.

The exposure of diorite is two miles in length from east to west, and extends one mile to the north to pass beneath the blown sand of Sandside Bay. It is somewhat triangular in shape, owing chiefly to its being overlapped on the north and west by the Old Red Sandstone. A thin strip of schist locally intervenes between the western margin and the Old Red Sandstone, and proves that the mass narrows in a lenticular manner to the south-west.

THE CRYSTALLINE SCHISTS.

Three main types of crystalline schists (quartzites, mica-schists, quartz-granulites) have been recognised in Caithness and their boundaries traced upon the map (Fig. 1, p. 19).

1. *Quartzites*.—The quartzites, generally pure white, and almost entirely consisting of granulitic quartz, are sometimes slightly pinkish

from the presence of a small amount of felspar, and secondary muscovite is then also present. The rock appears homogeneous, the planes of bedding and foliation being rarely distinct, but bedding and false-bedding may sometimes be seen crossed by the planes of foliation. On the other hand joints are a marked feature, and it is chiefly along these, as planes of weakness, that the rock breaks.

The quartzite has undergone the same metamorphism as the other schistose rocks, since it is folded and foliated along with them, but, from its massive homogenous nature, it has yielded less to the metamorphic agencies, and original pebbles may often be detected in it, whereas, in the other schists of the district, even small clastic grains are rare. The quartzite has also suffered less erosion than the other schistose rocks. At the present time the only well-marked hills of schistose rocks in Caithness consist of quartzite, and are confined to the Langwell Forest, where they range parallel with the strike of the folds and foliation of the schists.

Sal-vaich, Scaraben, Meall na Caorach, and the Eagle's Craig, mark the largest outcrop of the quartzite. It reaches a height of over two thousand feet on Scaraben, from which it plunges down sixteen hundred feet into the gorge of the Berriedale Water which separates Scaraben from the Eagle's Craig.

A second outcrop of quartzite appears along the same line of strike farther to the west. It extends from near Wag, on the Langwell Water, westwards, to cross the watershed at Creag nan Gearr and Creag Scalabsdale, where it reaches a height of eighteen hundred feet.

The Langwell Water, which occupies the hollow separating these outcrops, is eroding rocks of the mica-schist type. Thin bands of quartzite cross the hollow and may connect the two quartzite outcrops.

Farther to the north, remnants of another belt of quartzite, parallel to the last, form Cnoc an Eireannaich and Small Mount, which rise to over sixteen and fifteen hundred feet respectively. Eastwards from Small Mount this belt sinks beneath the Old Red Sandstone, and only comes to the surface again at Conachreag, north-west of Braemore Lodge.

South of Small Mount there is a smaller ridge, formed of quartzite, and capped by Old Red conglomerate, but surrounded on all sides by mica-schists.

2. *Mica-schists*.—These are strongly foliated rocks, consisting largely of muscovite and biotite, with strings and lenticles of granulitic quartz and felspar. They resemble the pelitic schists of the Moine Series in the Northern Highlands, to which they certainly belong, but garnets, which are usually abundant in the pelitic schists, are rather scarce in the Caithness rocks. Evidence has been obtained in Ross-shire that the pelitic gneisses were originally shales, which attained their present state through mechanical metamorphism.*

Mica-schists form a belt on the lower ground, south of and parallel with, the Scaraben Quartzite ridge. Good sections of these rocks are found in those branches of the Langwell Water which drain the Scaraben ridge, and locally in the Langwell Water itself between Altnabea and Wag. Mica-schists also form belts on either side of the

* "The Geology of Ben Wyvis, Carn Chuinneag, Inchbae, etc.," *Mem. Geol. Surv.*, 1912.

quartzite of Small Mount. Rocks of this type become scarcer farther north, and have not been recognised in other parts of Caithness.

3. *Granulitic Quartz-biotite-schists*.—These are granulitic rocks, consisting chiefly of quartz and felspar; muscovite and biotite are usually present in small scales. When micas are scarce, the rocks are massive. As mica increases in abundance, the rocks become more and more flaky, until they pass by almost insensible gradations into mica-schists. They are in every way identical with the granulitic gneisses of the Moine Series of the Northern Highlands. They form a belt, in the Langwell Forest, between the mica-schists and the Ord granite. Near the Berriedale Water, the belt increases in width, and comes into contact with the Scaraben Quartzite, since the belt of mica-schist, fringing the quartzite outcrop, dies out in this direction. Good sections of these rocks are found in the gorge of the Berriedale Water for three miles, and also in the branches of the Langwell Water. In the north-western part of the Langwell Forest, they are much interfolded with mica-schists, but gradually become the dominant type over the whole of the central and western parts of Caithness, wherever schistose rocks are exposed.

IGNEOUS ROCKS ASSOCIATED WITH THE SCHISTS.

THE AUGEN-GNEISS.

Igneous rocks of at least two ages are associated with the crystalline schists above described. The older of these rocks are chiefly granite-gneisses of the augen-gneiss type.

They have a very local development in Caithness. One exposure occurs at the "Fall Pool" on the Berriedale Water, two and a half miles below Braemore Lodge. It is only seen for about three hundred yards along the river bank, and is in contact with quartzite on its southern margin, and passes beneath the Old Red Sandstone at its limit upstream. Its junction with the quartzite is a line of fault.

Augen-gneiss again appears as two small inliers in the Old Red conglomerates, about six hundred yards farther up the river (Fig. 1). These inliers are only a few yards in extent, and one of them is chiefly bounded by the river alluvium.

A much larger exposure, mapped by Mr. Pocock, occurs near Corrichoich, north of Morven (Fig. 1). It is much obscured by drift and peat, but probably extends to the west for two miles along the strike of the schistose rocks. It appears to be in contact with the Strath Halladale granite on its northern margin, and is bounded by the Old Red Sandstone to the south. Parts of this exposure show little foliation.

There are pegmatites in the pelitic schist at one place near Corrichoich which are little deformed, and contain large felspar crystals, but the rock into which they are intruded is deeply decayed. Fragments and boulders of the augen-gneiss are common in the conglomerates of the Braemore district, and it is probable that considerably larger areas of the rock were exposed to denudation when these conglomerates were being laid down.

The augen-gneiss is a foliated pink biotite-granite, with large porphyritic orthoclase felspars. The latter, through deformation of

the rock, have formed augen, with tails of granulitic quartz around which are wrapped large folia of biotite, quartz, and felspar. The rock resembles in all details the augen-gneiss of Inchbae in Ross-shire, which has been proved to have been originally a porphyritic granite, injected into the sediments before the movements took place which changed the sediments into schists and the granite into a gneiss.* The augen-gneiss of Braemore, like that of Inchbae, is foliated with the schists.

HORNBLLENDE-SCHISTS.

Hornblende-schists form small lenticles and strings following the foliation planes of the schists in the Langwell Forest. They are rarely more than a few feet in width. They appear to have originally been small basic dykes or sills which have undergone metamorphism into hornblende-schists by movement.

THE ORD AND STRATH HALLADALE GRANITES.

These were intruded at a later date than the augen-gneiss, and the rocks which they penetrate had already been converted by dynamic agency into schists. They are biotite-granitites, of a prevailing pink colour, but sometimes grey, and the Ord granite is locally porphyritic with large orthoclase felspar crystals. The remarkable feature about these granites is that while locally they are foliated, at other points they are normal granites.

On the watershed, drained by the head waters of the Thurso, Berriedale, and Dunbeath Waters, the Strath Halladale granite forms a complex with the crystalline schists on an extensive scale. In this complex the granite is chiefly intruded along the foliation planes of the schists in large well-defined veins and in the finest *lit par lit* injections that can only be seen by aid of the microscope. Veins of granite and pegmatite also cut across the foliation planes without any definite orientation. Over large areas the blending of the igneous rocks and crystalline schists has been carried so far that it is often very difficult to decide whether the rock is essentially granite or schist. The method of intrusion appears to have been as much a soaking of the igneous magma into the schists with solution and recrystallisation of the minerals, as injection with displacement of the rocks. Various stages of incorporation and replacement of the mineral elements of the schists by the granite can be clearly observed in the field. Moreover, the siliceous and micaceous schists have yielded in a different manner to the igneous magma, and have blended with it to form different types of synthetic gneiss whose origin is often easily traced. These synthetic gneisses retain the original foliation planes of the schists in a somewhat broken and distorted manner. They pass over by further grades of magmatic incorporation into rocks with the appearance of foliated granites. The foliation planes of these granites, however, are faint, and the rocks merge directly into granites in which no signs of foliation can be detected. They can, moreover, be generally distinguished from the foliation planes of granites which have been subjected to pressure, such as the augen-gneiss described above, by

* "The Geology of Ben Wyvis, Carn Chuinneag, Inchbae, etc.," *Mem. Geol. Surv.*, 1912.

their disjointed broken character and absence of true parallelism for any great distance.*

THE DIORITE OF REAY.

This diorite was examined microscopically by Dr. Teall for Dr. Horne, who, in conjunction with Dr. Peach, mapped its outcrop. He states that "it is an augite-granite, or an augite-biotite-diorite. It consists of plagioclase felspar, quartz, pale green augite, hornblende, and biotite, with apatite, zircon, and sphene as accessories. The rock has sometimes a rough orientation of the minerals but appears to have no true foliation, nor are the minerals in a granulitic condition." The biotites in this diorite are very noticeable, being of a bronzy colour, recalling the biotites of the scyelite next to be described.

SCYELITE.

Scyelite occurs as a small boss, a few yards in extent, rising above the general level of the moorland, about one mile due north of Loch Scye (from which its name is derived), and lies within the granite area, not far from its boundary with the Old Red Sandstone.

The rock is stated to be an altered mica-hornblende-picrite by Professor Judd.†

A bronzy micaceous mineral is the most conspicuous element in the rock. This Professor Heddle regarded as talc, and he stated that the rock consisted of talc, with augite, serpentine, and magnetite.‡

The studies of Professor Judd showed that the original minerals in the rock have undergone alteration, the augite having become hornblende. Serpentine occurs after olivine or enstatite, while a magnesian mica, in an altered condition, and magnetite are also present. Professor Judd concludes: "In the scyelite of Caithness we have an interesting example of an ultra-basic rock of a new and hitherto undescribed type. It was originally a mica-picrite, with strongly marked ophitic structure, and exhibits evidence of some of its minerals having undergone schillerisation; but at the present time all the original minerals are represented by their pseudomorphs—augite by hornblende, olivine and enstatite by serpentine, and biotite by a curious hydrated form of that mineral."

Scyelites are now known from other localities in the Northern Highlands.§

C. B. C.

INLIERS OF METAMORPHIC ROCKS IN THE OLD RED SANDSTONE.

The remarkable irregularity of the floor of schist and granite on which the Caithness Old Red was laid down is shown by the overlap

* J. Horne and E. Greenly, "On foliated Granites and their relations to the Crystalline Schists in Eastern Sutherland," *Quart. Jour. Geol. Soc.*, vol. lii., 1896, p. 633.

† "Summary of Progress" for 1907, p. 86; 1909, p. 39; 1910, p. 41; 1911, p. 37. *Mem. Geol. Surv.*

‡ "On the Tertiary and Older Peridotites of Scotland," *Quart. Jour. Geol. Soc.*, vol. xli., 1885, p. 401.

§ *Mineralogical Magazine*, vol. v., 1884, p. 260.

§ "The Geology of Ben Wyvis, Carn Chuinneag, Inchbae, etc.," *Mem. Geol. Surv.*, 1912, p. 126.

along the western boundary, and by numerous inliers of older rocks, chiefly in the western areas. They are found at Dirlot, Loch More, and Caplaich Hill.

The Dirlot inlier is described in another chapter (p. 62).

The Loch More inlier is exposed in a small burn on the east side of the river Thurso, half a mile S.S.E. of Loch More (Sheet 110). For a short distance above and below the footbridge, micaceous schists are exposed. Less than a hundred yards below the bridge, red and yellow shales and sandstones (Old Red) are faulted down against these schists. But about 90 yds. above the footbridge, opposite an old stone ruin, a normal junction of the Old Red sediments with the schists is seen in the burn. Resting on the schist is a basal breccia, three inches to one foot in thickness, covered by red shales and bands of yellow sandstone. A few yards farther upstream the schists are brought up again, and careful examination of the section shows that they are thrust over the red shale, the plane of movement being inclined eastwards at a very low angle. The schists are seen for a short distance farther up the stream, but about 130 yds. above the footbridge the basal breccia again appears; the remainder of the section is in red shales, grit, and sandstone (Old Red). The whole section is small and poorly exposed, and is chiefly of interest on account of the clear evidence of thrusting in the Old Red rocks, the movement coming from the east.

The Caplaich Hill inlier of red biotite-granite is situated in the extensive peat mosses that cover the south-western part of the county. As the exposures are small and discontinuous, the actual configuration of the inlier is somewhat indeterminate, although the relation between the granite and the sediments can be made out with fair accuracy.

The junction between the Old Red and the granite is clearly seen on the low hill known as Sithean na Gearra, and in rock outcrops rather more than half a mile to the south-east. The basal bed of the sediments is a granitic arkose, in which the feldspars are as fresh and angular as in the granite itself. In fact, it is often extremely difficult to distinguish the arkose from the granite; the line of demarcation between the two rocks can sometimes only be detected by the truncation by the arkose of the thin pegmatite veins that traverse the granite.

Bands of an angular granite-breccia are often seen associated with the arkose, the interstices between the granite fragments being filled with red and chocolate coloured mudstone. Exposures of this rock can be seen at many points round Caplaich Hill, particularly in three small outcrops $1\frac{1}{4}$ mile north of the summit. The infilling of red mudstone between the granite fragments often gives the rock the appearance of a tessellated pavement.

Small sections of arkose and granite can be observed in the upper part of the Caplaich Burn, and farther downstream, south of Sithean Corr-meille, there is a high bank where the granite is exposed. In all these cases the rock is much decomposed, and for the most part has weathered down to a gritty sand. In the granite exposures, however, the thin pegmatite veins are still preserved intact, in spite of the greatly softened condition of the rock.

R. G. C.

CHAPTER III.

THE BARREN GROUP OF CONGLOMERATES, ARKOSES, ETC.

THE BERRIEDALE OUTLIER.

THE crystalline rocks reach the coast at Badsallach a short distance north of the mouth of the Berriedale Water and isolate a part of the Old Red Sandstone from the main body of the formation (Fig. 1).

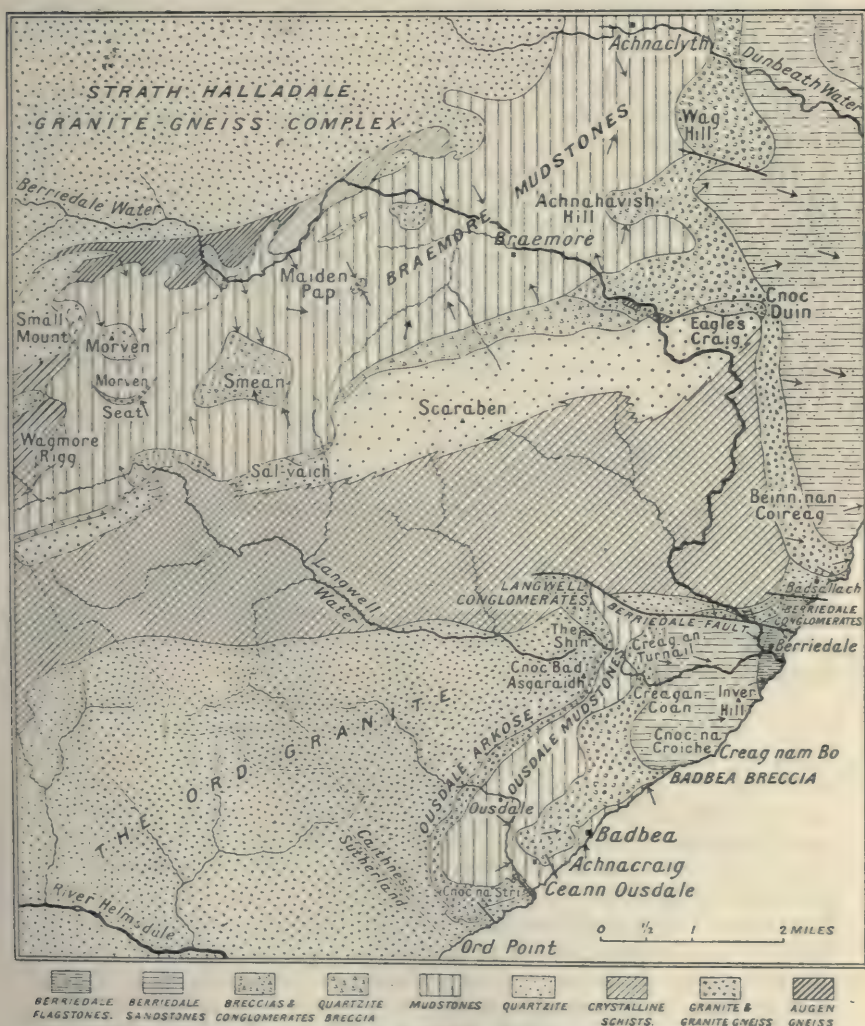


FIG. 1.—Map showing the Old Red Sandstone of the Berriedale Outlier and of the Morven and Braemore Districts, with its relation to the foundation crystalline rocks.

Along the four and a half miles of coast-line between Ceann Ousdale and Badsallach practically the whole thickness of the rocks of this outlier is exposed in continuous section. Interrupted sections of these rocks extend inland one mile up the Berriedale Water and more than two miles up the Langwell Water and Ousdale Burn. The examination of these, in conjunction with other scattered exposures, has allowed of lines being drawn on the map separating the four well-marked groups of strata displayed in the sea-cliffs. The prevailing dip of the rocks of this outlier is to the east and east-north-east. The basement beds occupy the southern end of the coastal section at the mouth of the Ousdale Burn, and thence extend inland as an irregular belt. The uppermost beds of the outlier occupy the sea-cliffs near the common exit of the Berriedale and Langwell Waters. The rocks of the outlier for the most part overlie the Ord granite, but in their farthest north-west extension step fully half a mile on to the crystalline schists.

The northern boundary, in part a faulted one, stretches three miles inland from Badsallach in a westerly direction.

On the coast south of the granite at Badsallach conglomerates form a local base at a much higher horizon than the arkoses of the western boundary. Conglomerates are also found inland resting on the granite along its northern boundary, but an east-and-west fault, the Berriedale fault, which reaches the coast at a point about half-way between Badsallach and the mouth of the Berriedale Water, brings them against sandstones higher in the sequence, and, farther west, forms a northern boundary to the Old Red Sandstone, faulting lower and lower beds in succession against the crystalline schists and granite.

The four groups of strata in this outlier are as follows :—

4. Berriedale Sandstones and Flagstones.
3. Badbea Breccia.
2. Ousdale Mudstones.
1. Ousdale Arkoses and Langwell Conglomerate.

THE OUSDALE ARKOSES AND LANGWELL CONGLOMERATE.

The Ousdale Arkoses are well exposed for a quarter of a mile in the gorge at the mouth of the Ousdale Burn, and also for a short distance in the sea-cliff.

In the cliff section the junction between the Ord granite and the arkose is a fault, but this is in all probability a small one. The two rocks are wonderfully alike in their pink colour, massive character, and mode of weathering. Bedding planes are difficult to detect in the arkose, and are certainly not accentuated by weathering. Even in hand specimens the likeness between the two rocks is very marked. The large pink porphyritic feldspars derived from the granite are scattered irregularly through the arkose without any noticeable orientation, and are remarkably fresh. The arkose, moreover, is frequently as coarse-grained as the granite. The interlocking growth of quartz and feldspar, characteristic of the igneous rock, is, of course, absent, but the margins of fragments of granite in the arkose are often very obscure. Pebbles or angular pieces of vein-quartz and crystalline schists may occasionally be detected.

The fault separating the arkose and granite traverses the cliff in a west-south-westerly direction, but continues nearly parallel with the coast-line for about a mile, and is then cut off by another fault nearly at right angles to it. This fault throws down to the south-west, and brings the junction of the arkose and granite on to the rocky slopes above the cliff. The basement rocks are here rather more conglomeratic in character, but the fragments are entirely of granite and lie in an arkose matrix. The granite and arkose are also seen in close conjunction in the burn north of Ord Point.

The arkose crosses the main road immediately to the north of this burn, and gradually swings round to the north and north-east towards Ousdale, where it is again exposed in the burn near the bridge. From Ousdale it must follow the granite boundary in a north-east direction to Cnoc Bad Asgaraidh, but the intervening ground is obscured by peat. The arkose is exposed in the small crags on the east side of this hill, and seems to be dipping steeply away from the granite exposed nearer the cairn. Crossing the Langwell Water the outcrop swings round to the north-west, and the base line follows the north bank of the river to the great bend at the Shin. It then continues along the burn which flows southwards into the Langwell Water at this point, and passes from the granite on to the crystalline schists. Arkose is exposed at several points along the roadside on the northern bank of the Langwell Water. It lies on granite but gives place above to a conglomerate formed of granite and schist fragments. As the boundary between the granite and schist is approached the fragments of the latter rock become more numerous, and the glaciated exposures of conglomerate which rise out of the peat about half a mile north of the Shin consist entirely of small subangular and rounded fragments of schist and quartzite, but are enclosed in an arkose matrix. In the burn referred to above conglomerates of granite and schist fragments are exposed for over half a mile until they are suddenly terminated against the crystalline schists by the Berriedale fault.

The basement arkose and conglomerate group is probably nowhere of great thickness. Between Ousdale and the Langwell Water its outcrop is from 500 to 600 ft. in width. It covers a wider area at Cnoc na Stri, near the mouth of the Ousdale burn, but this is partly due to faulting. North of the Langwell Water it widens to one-third of a mile, and the arkoses are replaced by conglomerates, and it is likely that the increased breadth is due to greater accumulation of coarse fragmental materials.

THE OUSDALE MUDSTONES.

For one and a half miles north of the mouth of the Ousdale Burn the cliffs are formed by mudstones overlying the arkoses. Except near the burn, where the rocks dip to the north-east at angles of 20° to 30° , the mudstones which form the cliff dip inland to the north and north-west to pass at a short distance beneath the overlying Badbea Breccia, which forms the steep seaward slope above the cliff. At their farthest northward extension in the coast section the dip again suddenly swings round to the north-east, and the overlying Badbea Breccia descends the cliff to sea-level.

Inland the mudstones are met with in the burn as far as Ousdale,

and also in all the branches below Ousdale bridge. In the burn section they dip to the north-east at angles of 20° to 40° , but to the east of Ousdale the dip swings round to the north and north-north-west. The mudstones between Ousdale and the coast are therefore arranged in a shallow trough whose axis runs in a north-east direction.

A good section of these rocks is also exposed in the Langwell Water to the north-east of Cnoc Bad Asgaraidh, where the beds are dipping at angles varying from 20° to 50° . The rocks of this group consist chiefly of Indian red, chocolate, and to a less extent of pale green and bluish-green mudstones, which split with some difficulty along the bedding planes, although these are finely laminated and are accentuated by exposure in the sea-cliffs. They usually break up into small fragments with irregular or conchoidal fractures, and only form flags when they are sandy or micaceous.

The cliff scenery of the mudstones is very rich in colour from the alternation of red, purple and greenish bands. Some beds are partly red and partly green, usually in a blotched or spotted manner. Interbedded in places with the mudstones are pale pink, fine-grained sandstones, which are usually more calcareous and weather with a honey-combed surface. In the lower part of the group bands of fine-grained arkose are intercalated in the mudstones, forming passage beds from the coarser arkoses to the mudstones. The junction with the overlying Badbea Breccia, on the other hand, is very abrupt and suggestive of unconformity. The thickness of the Ousdale mudstones is about 700 to 800 ft.

THE BADBEA BRECCIA.

About half a mile south of Cnoc na Croiche the Badbea Breccia forms the coast for about a quarter of a mile. The cliff is here more than usually accessible owing to a series of landslips along joints and small faults parallel with the coast. The result is a step-like arrangement of small cliffs exposing faces of the breccia, terraces covered with vegetation, and great screes of fallen blocks, the whole forming a rugged slope some 400 ft. from the top to the narrow beach at the base. The great vertical joints which traverse the breccia allow water to percolate downwards to the level of the underlying mudstones, and it is along the junction of the two formations that slipping is initiated.

The remarkable nature of the Badbea Breccia has been commented on by Sir Archibald Geikie.* The fragments of quartzite, schist, and granite of which it is chiefly composed, are very angular, the larger and smaller fragments showing an equally unrolled condition. There are also small pieces of a reddish sandstone derived in all probability from beds lower down in the series. Large broken fresh crystals of felspar like those of the basement arkose are frequent. All these rock fragments are enclosed in a matrix of arkose. The rock is rudely bedded, but with little sign of orientation of the included fragments. The thickness of the Badbea Breccia is probably about 300 ft.

The junction with the underlying mudstones is well exposed in the face of the cliff to the south of the landslip, from which it can be

* "Old Red Sandstone of Western Europe," *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 379.

easily examined. It has every appearance of unconformity since the bedding planes of the mudstones are truncated by the base of the breccia. Although the Badbea Breccia has so limited a development in the coast section it covers a wide area inland. The outcrop of the breccia forms Creagan Mòr, and is continued as a cap to the higher ground between the Ousdale Burn and the sea as far south as Achnacraig, but the rocks dip steadily to the east and east-north-east, and appear to take no part in the synclinal arrangement of the underlying mudstones. The breccia continues to have an outcrop nearly a mile wide to the north of the main road, where it forms the rounded Creagan Cosach and Creagan Coan. Along the double bend in the Langwell Water, immediately above the Langwell plantations, the breccia is exposed at several points. The best section is on Creag an Turnail, on the north side of the river, where the junction of the breccia with the underlying mudstones was laid bare in cutting the estate road. The breccia is like that at Badbea, but fragments of schist and quartzite are relatively in greater proportion to those of granite than in the Badbea section. The underlying mudstones are dipping at a considerably steeper angle and in a slightly different direction, and the appearance of unconformity is even more marked than in the section at Badbea.

The actual junction of the breccia with the overlying sandstone is nowhere clearly seen. Even in the cliff section it is involved in the area of landslip, but the upward passage is everywhere into fine-grained arkoses, which are of considerable thickness, and form the basal numbers of the next group.

THE BERRIEDALE SANDSTONES AND FLAGSTONES.

These are so arranged as to dip towards a point seaward of the mouth of the Berriedale Water. South of the Langwell Water, the dip is to the north of east, but north of the mouth of the river a southerly dip becomes more and more marked as one passes northward to the Berriedale fault. Between the fault and the local base at Badsallach the rocks are dipping to the south-east and south-south-east.

The highest horizon exposed in these beds must lie at the mouth of the Berriedale Water.

The conglomerates which flank the granite and schist in the coast section at Badsallach dip to the south-south-east and form the local base of the Old Red Sandstone. The conglomerate lies on granite but is faulted against the main mass of granite and schist. About three hundred yards inland conglomerates are again met with and can be followed into the hollow of the Berriedale Water where they form an outcrop two hundred yards wide. They rest upon granite and schist, and can be traced to pass up into the sandstone exposed along the river banks. The conglomerates cross the Berriedale Water, and are exposed three hundred yards farther up, dipping to the south-south-east. To the south they are truncated by the east and west Berriedale fault, which throws down against them sandstones higher in the sequence. The fragments of schist and granite forming these conglomerates lie in an arkose matrix and are more or less rounded. Owing to the influence of the Berriedale fault it is impossible to compare the thickness of the sandstones and flagstones exposed in the

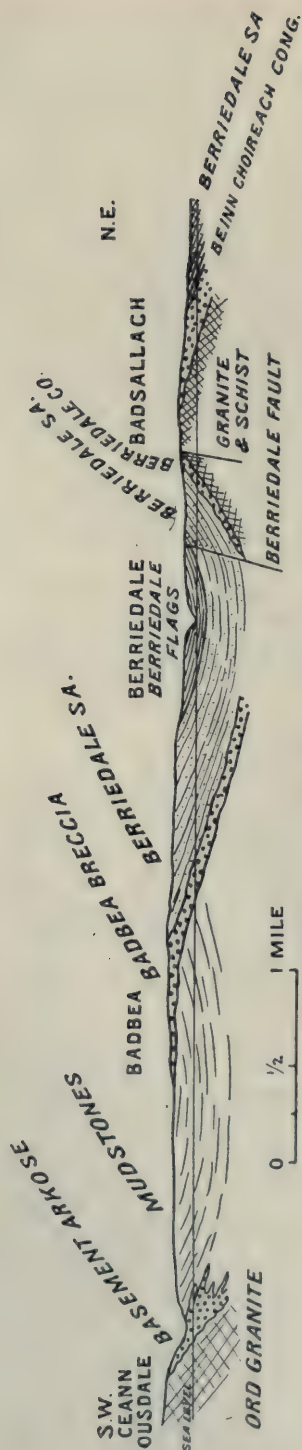


FIG. 2.—Horizontal Section of the Coast-line between Ceannt Ousdale and Badsallach.

coast between Berriedale and the local base at Badsallach, and that between Berriedale and the breccia at Badbea. The upward passage from conglomerates into sandstones at Badsallach proves, however, that we are not dealing with the lower basal conglomerate of the Ousdale area, and the conglomerates at Badsallach and in the Berriedale Water must represent either the Badbea Breccia or a somewhat higher horizon. It will be shown later that the conglomerates to the north of the Badsallach local base, which are presumably of about the same age as those to the south, can be traced in the Braemore area to pass into conglomerates interbedded with the finer sediments. These interbedded conglomerates directly overlie the Mudstone Group, and underlie sandstones and flagstones, and therefore lie at about the same horizon as the Badbea Breccia.

The rocks of the Berriedale Sandstone group may be subdivided into a lower series of arkoses (Berriedale Sandstones) and an upper one of more flaggy beds (Berriedale Flags). The Berriedale Sandstones consist of reddish fine-grained arkoses with subordinate flaggy layers. They occupy the coast section between the conglomerate at Badsallach and the Berriedale fault, and again from Inver Hill south, for more than a mile. They also form part of the section in the Langwell Water above its junction with the Berriedale Water. The Berriedale Flagstones are only found near the mouth of the Berriedale Water, and in the coast sections on either side of the mouth of the river. The beds are for the most part red in colour, but have intercalated with them grey and greenish flagstones. It is in these beds that C. W. Peach is reported to have obtained a specimen of *Dipterus*.*

* "Old Red Sandstone of Western Europe," *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 387.

The Berriedale Sandstones must have a thickness of over 1300 ft., and there are probably 500 ft. of the Berriedale Flagstones exposed near Berriedale.

BRAEMORE AND MORVEN DISTRICT.

North of the Scaraben ridge, a part of the main area of the Old Red Sandstone extends as a tongue-shaped prolongation for more than ten miles, in a west-south-westerly direction, to the Caithness-Sutherland march. At the eastern end, between Cnoc Dùin and Achnaclyth, this mass has a width of more than three miles. For eight miles to the west to beyond Morven, it continues to have a breadth of more than two miles, but west of Wagmore Rigg, in the region of the headwaters of the Langwell, it is abruptly truncated by a north and south boundary which only allows a narrow strip, half a mile in width and let down by a fault on its north side, to continue as far as The Child's Seat on the Sutherland march (Fig. 1, p. 19).

The rocks are arranged in a syncline, whose axis runs rather south of the centre, and parallel with the length of the tongue-shaped outcrop (Fig. 3).

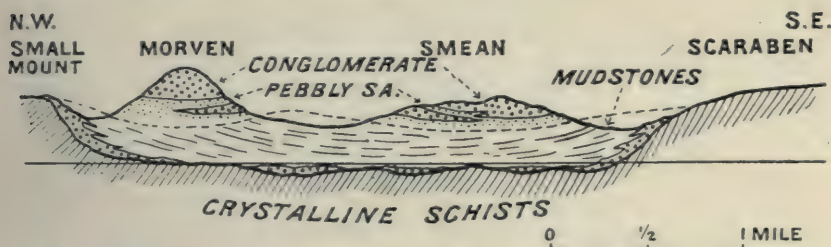


FIG. 3.—Horizontal Section across the Old Red Sandstone of the Morven District.

The Old Red Sandstone for the most part forms lower ground than the surrounding granites and schists, but, in places along its boundary with these rocks, rises to nearly 1500 ft., and, in the centre of the area, forms still higher elevations, reaching to 1500 ft. on Maiden Pap and Smean, and 2313 ft. on Morven, the highest point in Caithness. These tops consist of caps of conglomerate, forming outliers on the red mudstones and sandstones that occupy the greater part of the trough. The latter, for the most part, are dipping towards the axial line of the trough, but the direction and angle of dip are very changeable, and they often lie at steep inclinations. The conglomerates of the outliers and some pebbly arkoses, which immediately underlie them, have much gentler angles of dip. Conglomerates and breccias are also found locally along the junction of the Old Red Sandstone and the crystalline rocks. The Old Red Sandstone of this area may therefore be conveniently described under the following groups:—

4. Conglomerates of Morven, Smean and Maiden Pap, etc.
3. Braemore Mudstones and Sandstones.
2. Fringing Quartzite Breccias of Scaraben, etc. These are not confined to one horizon.
1. Local Basement Conglomerates of Braemore.

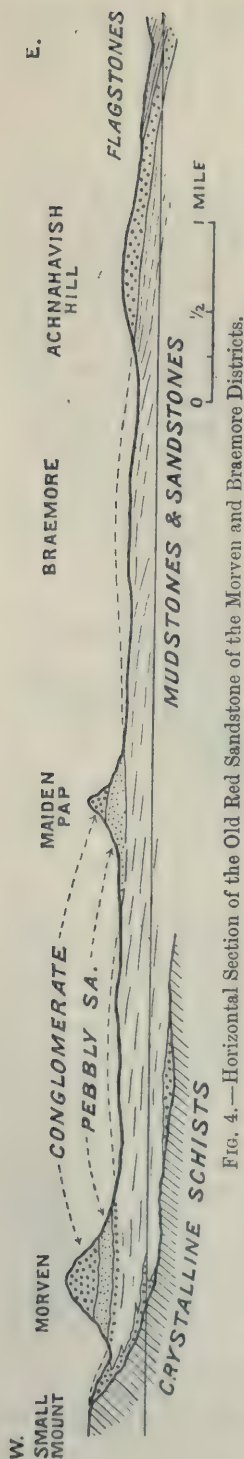


FIG. 4.—Horizontal Section of the Old Red Sandstone of the Morven and Braemore Districts.

1. LOCAL BASEMENT CONGLOMERATES OF BRAEMORE.

These are only seen in the hollow of the Berriedale Water below Braemore. They rest directly upon the augen-gneiss in the bed of the river, and to the north-west pass beneath the Braemore Mudstone and Sandstone. The rocks consist of blocks, boulders and smaller fragments of quartzite, augen-gneiss, granite and mica-schist imbedded in an arkose matrix. Some of the boulders, especially those of augen-gneiss are large and well rounded.

2. QUARTZITE BRECCIAS OF SCARABEN, ETC.

A continuous strip of these rocks extends for five miles along the northern slopes of Scaraben across the Berriedale Water. Quartzite breccias are again met with wrapping round the northern flank of the Eagle's Craig, the farthest westward extension of the quartzite outcrop. The breccias consist entirely of sharply angular fragments of quartzite cemented by quartzite debris. They are pure white, and require close examination to distinguish them from the quartzite rock against which they rest. No great thickness of these rocks is anywhere met with. They occur rather as patches sticking to the faces of the quartzite rock, and on the north slopes of Scaraben rise above the 1000-ft. contour. Similar quartzite breccias occur up to 1250 ft. on the flanks of Creag Scalbsdale, and to about 1300 ft. on the east end of Small Mount.

3. THE BRAEMORE MUDSTONES AND SANDSTONES.

These rocks are exposed in many of the streams which traverse the peat-covered stretches between Braemore and The Child's Seat. There are also many sections showing them round Achnaclyth. Similar rocks are found in the area east of Ben Alisky.

In sections in the branches of the Langwell Water south of Morven, these rocks may be seen lying directly on the crystalline schists, without the intervention of any conglomerates.

The dip in the Braemore mudstones and sandstones is often steep and varies much more at short distances, from point to point, than that usually found in the flagstone areas of

Caithness. The rocks are invariably red, purplish, or greenish in colour, and are fine-grained arkoses, sandstones or mudstones. They are, in most respects, like the rocks of the mudstone group of the Berriedale outlier, with which they are without doubt to be correlated. Sandstones are, however, relatively more abundant, and the finer-grained beds are often more micaceous, which tends to their splitting like flagstones.

Several hundred feet of the highest part of these beds, which underlie the conglomerates of Morven, Smean, and Maiden Pap, consist of pebbly arkoses inclined at gentle angles like the overlying conglomerates. On Morven, in addition to the conglomerate capping the hill, there are others which apparently underlie these pebbly arkoses. They are exposed at Morven Seat, at a height of 1000 ft., on the south side of the hill. These pebbly arkoses, associated with the conglomerates, were probably laid down under different conditions to the red mudstones and sandstones forming the lower part of the series.

An estimate of the thickness of this group of beds is difficult to make. Moreover their true base may be nowhere exposed in the Braemore region. On the Dunbeath Water, the beds are dipping more or less continuously in an easterly direction for 3000 yds. between the granite and the overlying conglomerate. The dip varies from 5° to 50° , but with an average of 10° there would be a thickness of 1500 ft. It is therefore possible that, in this region, some of the lowest beds are on a lower horizon than the lowest beds at Ousdale.

4. THE CONGLOMERATES OF MORVEN, SMEAN, MAIDEN PAP, ETC.

These are chiefly represented by a great mass of conglomerate, which extends from Cnoc na Feadaige, near the Berriedale Water, for at least six miles in a northerly direction. It is continuous to the south with the local basement conglomerate, which stretches from Cnoc Duin to the sea at Badsallach. In its northerly crop it caps Achnahavish Hill and Wag Hill, and overlies the Braemore Mudstones and Sandstones. It crosses the Dunbeath Water about one mile below Achnaclyth, and about two miles farther north forms Cnocan Conachreag. North of this point, on account of the thick mantle of peat, it has been found impossible to follow the conglomerate for more than a mile, and the outcrop has therefore been drawn on the map as if it died out in this direction. It may, however, have a greater extension, and is possibly to be correlated with the band of conglomerate which overlies the red mudstones and sandstones of the Shurrery area.

The conglomerate outcrop has a width of over a mile on Achnahavish Hill and Wag Hill, but this is partly owing to the form of the ground. In the Dunbeath Water its outcrop is nearly half a mile wide, and its thickness is probably over 250 ft.

In many parts of its extent, as at the Wag Hill and Cnocan Conachreag, the conglomerate forms a steep escarpment facing west, where it overlies the Braemore Mudstones and Sandstones. One of the best sections is in a quarry, by the roadside, on the south side of Achnahavish Hill. It is here fairly well bedded, and consists of small angular fragments and rounded pebbles of quartzite, quartzose schists, mica-schists, granite, and augen-gneiss. The augen-gneiss fragments must have travelled from the area farther west. Owing to a small fault

which traverses the quarry, the junction with the underlying mudstones is exposed at one place. The latter are dipping at steeper angles than the conglomerate and in a slightly different direction. The ice-worn top of Wag Hill exposes conglomerates of rounded and subangular fragments of quartzite, schist, and granite. Most of the fragments are small, but some are more than a foot across. At Cnocan Conachreag the conglomerate forms a cliff 40 ft. high overlying mudstones. The mudstones dip to the east-south-east, while the overlying conglomerate dips to the east-north-east at gentler angles. The line of junction between the conglomerate and the mudstones, here and at Achnahavish Hill, has thus every appearance of unconformity. The conglomerate is well bedded with rounded pebbles of granite, schist, and quartzite. Some of the granite boulders are 1 or 2 ft. in diameter.

The other conglomerate masses, overlying the Braemore Mudstones and Sandstones, are those of the Morven, Smean, and Maiden Pap outliers (Fig. 4). The Morven conglomerate dips at very gentle angles to the south, and must be over 600 ft. thick. The highest beds are well stratified, and consist chiefly of rounded and subangular fragments of quartzose schist. The lower beds contain boulders, chiefly of augen-gneiss and granite, 6 ins. or more in diameter. The base of the conglomerate is obscured on most aspects of the hill by fallen blocks, but on the north side several hundred feet of red arkoses, with pebbles of quartzite and granite, underlie the mass.

The conglomerate of Smean lies to the south-east of that of Morven, and its base is about 250 ft. lower. The beds are arranged in a gentle syncline, and dip to the north-north-east and south-south-west. The stones forming the mass are rounded and subangular, and consist of granite and quartzite. There are also slabs of a red sandstone. Some of the blocks of quartzite range from 6 ins. to 2 ft. in diameter. A similar conglomerate is found on the north face of Sal-vaich at the same elevation, and replaces the quartzite breccias. At the western end of Smean, and separated from the other crags by peat, there is a small crag of conglomerate at a considerably lower elevation. It lies at the same level as the conglomerate of Morven Seat along the strike of the rocks, and may form part of the same mass. On the eastern and northern slopes of Smean, beneath the conglomerate, there are red arkoses with pebbles similar to those of the north flank of Morven.

The conical mass of conglomerate, which caps Maiden Pap, is nearly horizontal, and about 300 ft. thick. It lies in a shallow trough of pebbly red arkoses. The conglomerate is more pebbly near the base, the top showing more subangular blocks of granite and quartzite.

Morven, Smean, and Maiden Pap, therefore, probably include parts of more than one sheet of conglomerate. The highest mass of Morven contains more augen-gneiss fragments, which are evidently derived from the north, while the conglomerate of Smean contains more quartzite blocks derived from the Scaraben ridge.

The mudstones and sandstones in the vicinity of these hills evidently underlie the pebbly arkoses which form their flanks. They have a much more irregular dip and strike than the overlying beds. The pebbly arkoses appear to lie above the 1000-ft. contour everywhere, and no mudstones occur above this altitude. There are no definite signs of unconformity at the base of the conglomerate on these hills,

such as are found at the junction of the conglomerate and mudstones to the east of Braemore. It is possible, however, that the lower conglomerates of Morven Seat and the pebbly arkoses are lying unconformably on the mudstones and sandstones.

The presence of augen-gneiss fragments in the conglomerates of Achnahavish Hill shows that the main mass of conglomerate must have extended farther to the west.

*The Correlation of the Rocks of the Braemore and Morven District
with those of the Berriedale Outlier.*

The quartzite breccias of the slopes of Scaraben and elsewhere are evidently screes formed on steep slopes, and were overlapped by beds of varying horizons. At low levels they are in contact with conglomerates which, in the hollow of the Berriedale Water, pass beneath the mudstones and sandstones of the Braemore district; whilst on the Eagle's Craig they pass laterally into the conglomerates, extending northward to Cnocan Conachreag, which were laid down on an eroded surface of these beds.

The Braemore Mudstones and Sandstones are evidently on the same horizon as the mudstones of the Berriedale Outlier. In both districts these beds are limited above by a conglomerate which, at least locally, lies upon them unconformably. The correlation may, therefore, be drawn up in tabular form as follows:—

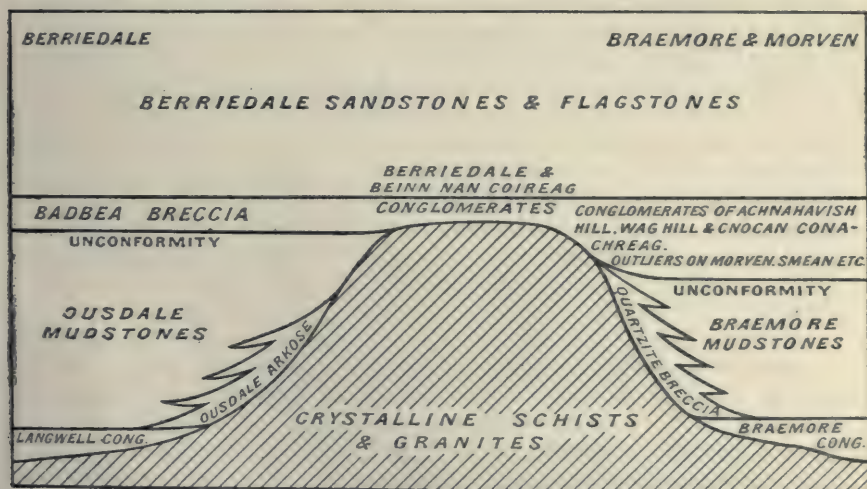


FIG. 5.—Diagram to illustrate the correlation of the rocks of the Braemore and Morven Districts with those of the Berriedale Outlier.

THE DUNBEATH DISTRICT.

THE CONGLOMERATES OF BEINN NAN COIREAG, CNOC DÙIN, ACHNAH-VISH HILL, WAG HILL, CNOC NA FEADAIGE, AND CNOCAN CONACHREAG.

North of the Berriedale conglomerate at Badsallach, a steep broken slope of granite and schist faces the sea for rather more than

a quarter of a mile, and then conglomerates reappear lying on the crystalline rocks at the top of the slope. The conglomerate dips to the east-south-east and east, but farther north dips to the north-east, and gradually descends into the cliff section. It reaches sea-level about 300 yds. north of Ceann Leathad nam Bò, and continues to form the cliff for rather more than 200 yds.

At Screadan the whole height of the cliff is formed by an overlying red arkose. Passing inland the conglomerate has an outcrop with a breadth of 1000 yds. on Beinn nan Coireag, where it dips to the east and east-north-east, and is probably about 300 ft. in thickness. The outcrop extends northward to Cnoc Dùin, where it becomes continuous with the quartzite breccias referred to in a former paragraph. Throughout this distance the conglomerate lies on quartzose schists, and consists of pebbles and angular fragments of schist and quartzite in a red sandy matrix. Fragments of granite are scarce except near Badsallach.

North of Cnoc Dùin the conglomerate leaves the crystalline rocks and becomes a mass lying on the Braemore Mudstones and underlying the Berriedale Sandstones, its outcrop extending through Cnoc na Feadaige, Achnahavish Hill, Wag Hill, and Cnocan Conachreag, as described above (p. 27).

THE BERRIEDALE SANDSTONES OF THE DUNBEATH AREA.

The boundary of the Beinn nan Coireag conglomerate with the overlying red arkoses of Screadan can be traced inland past Cnoc Dùin to Cnocan Conachreag. Red arkose sandstones, similar to those at Screadan, everywhere overlie the conglomerate in the inland sections. They are well exposed in the rock gorges of the Dunbeath Water, and can be traced farther northwards for about three miles, but are then lost under the vast stretch of peat that covers the area north of Cnocan Conachreag. In the coast section, red arkoses are found as far as Stùrr Ruadh, and this mass of arkose sandstones, 600 ft. thick, may be compared with the great mass which overlies the breccia of Badbea, where it forms the cliff 400 ft. high, south of Cnoc na Croiche.

At Stùrr Ruadh the arkose passes up into alternations of mudstones and sandstones of a prevailing red colour, but also with greenish and greyish bands. These form the cliffs from Stùrr Ruadh to Ceann Badaidh na Muic, but for a considerable distance the strike of the beds is parallel with the coast-line and with several small crushes which flank a large fault which lies seaward of the cliff face. The rocks are turned on end in the fault line, and stand up as reefs parallel with the coast. The continuation of this fault to the north forms a big smash in the promontory on the north side of Dunbeath Bay. The red mudstones and sandstones are exposed inland in many places in the Ramsraigs district, and in the fine sections in the Achorn Burn and the Dunbeath Water. Their upper margin is difficult to define in the coast section. Near Dunbeath Castle they seem to pass laterally into beds with intercalations of flagstones. In the Dunbeath Water, a short distance below Balantrath, they pass up into beds with alternations of red, green, and dark grey colours. These are more flaggy in character, and have occasional thin bands of impure

limestone, which weather into black papery alum shales, and contain fragments of fossil fish.

These, the Berriedale Flags, form the coast-line near Dunbeath, and considerable areas inland. Before proceeding to their description, it will be well to set in tabular form the correlation of the beds in the districts south and west of Dunbeath.

<i>Braemore District.</i>		
<i>Berriedale Outlier.</i>	<i>Morven District.</i>	<i>Dunbeath District.</i>
5. Berriedale Flags.	Wanting through denudation.	Berriedale Flags.
4. Berriedale Sandstones.		Berriedale Sandstones.
3. { Badbea Breccia, and Berriedale Conglomerates.		Beinn nan Coireag, Achnahavish, and Cnocan Conachreag Conglomerates.
2. Ousdale Mudstones.	Braemore Mudstones.	
{ Fringing Quartzite 1. { Arkoses of Ousdale. of Langwell and Braemore.	Breccias of Scaraben and Basement Conglomerates	
		Wanting, in coast region, through overlap.

THE BERRIEDALE FLAGSTONES OF THE DUNBEATH AREA.

A line has been drawn on the map to show the approximate boundary between the Berriedale Sandstones and Berriedale Flags in the Dunbeath district. It extends from the coast near Ceannt Badaidh na Muic to cross the Dunbeath Water about one mile above the bridge at Dunbeath. It continues in a north-westerly direction to the west of Cnoc na Maranaich, and thence due north towards Loch a' Cheracher, but soon ceases to be traceable, owing to the thick mantle of peat. There are good sections of these beds on the coast north of Dunbeath Castle, in quarries near Knockally, and on the Dunbeath Water and its branches. A band of impure limestone on the north bank of the Dunbeath Water, near its junction with the Houstry Burn, contains fragments of fossil fish. Thin limestone bands also occur on Cnoc na Maranaich, but no fossils were observed.

C. B. C.

AREA BETWEEN DUNBEATH AND LATHERON.

The strata seen in the stream sections above and below Dunbeath comprise alternations of hard yellow sandstone and bands of rough dark blue flagstone, weathering olive-green. On the headland on the north side of Dunbeath Bay there is extensive brecciation and faulting, culminating in a large fault with an easterly downthrow, of which there is an excellent section in the broken cliffs at Poll Gorm, 500 yds. north-east of the harbour. These disturbances mark the southerly continuation of the great Latheron fault, but the main dislocation lies seaward, the displacements on the coast section at this point not being more than a few hundred feet.

In the midst of the fault zone, about 250 yds. east of Dunbeath harbour, a band of rough, dark, calcareous flag is seen, some 6 ft. in thickness; in the centre there is a 6-in. band of slaty "limestone" with poorly preserved fish remains.

On the east side of the large fault at Poll Gorm, thin-bedded dark flagstones, weathering pink and yellow, alternate with thin bands of

light grey grit; amongst the flagstones are numerous thin beds of light grey "calmstone," with a creamy weathering, and half an inch or so in thickness.

In the cliffs north of Cleit Mhòr higher strata appear, much darker in tint, and with a greater proportion of rough shaly flagstone. These beds belong either to the upper part of the Helman Head Beds or the lower part of the Wick Flags, but a full investigation is prevented by the inaccessibility of the cliffs at this part of the coast. R. G. C.

The fault zone seen north of Dunbeath Harbour emerges again in the cliffs north of Uamh Ròn, where the flagstones are seen upturned against the fault at an angle of 12° from the vertical.

Round Janetstown Harbour there are good sections of gently inclined strata on the upthrow side of the fault. The sequence is continued from the low cliffs on the south side of the harbour up the hillside to Knockinnon, and is roughly as follows:—

	Ft.
Bands of calcareous sandstone with subordinate dark flagstones ..	40
Shale with a limy band with fish remains	12
Bands of calcareous sandstone and some dark flagstones ..	288
"Limestone" with fish remains (exposed along roadside S. and E. of Knockinnon.)	2
Sandstone, more or less calcareous, often with carious weathering: occasional shaly bands	128

E. M. A.



CLIFFS OF CONGLOMERATE WITH VERTICAL JOINTING. South of Gearty Head.

CHAPTER IV.

DISTRICT BETWEEN LYBSTER AND WICK.

THIS chapter includes the description of the rocks in the coast-line between Lybster and Wick, and a strip of country about two miles in width bordering the coast. They are involved in the Sarclet Anticline and the Latheron and Ackergill Synclines, and are traversed by several powerful faults.

THE SARCLET ANTICLINE.

The rock groups recognised in this part of the coast section to the north and south of Sarclet are given below in order of succession :—

Wick Flagstone Group.	{	8. The Wick Flags.
		7. The Red Beds of Girston and Hillhead.
		6. The Helman Head and Clyth Beds.
		5. The Ellens Goe Conglomerate.
Basement Group.	{	4. The Ulbster and Ires Goe Sandstone.
		3. The Ulbster and Riera Goe Mudstones.
		2. The Sarclet Sandstone.
		1. The Sarclet Conglomerate.

The accompanying sketch map (Fig. 6) shows the extent of the coast sections of the above groups to the north and south of Sarclet, their outcrops near the coast, and the faults by which they are dislocated. An attempt has been made to show, by means of strike lines and dip symbols, the arrangement of the rocks in the Sarclet Anticline, and those parts of the Latheron and Ackergill Synclines which enter into the district.

Several large faults, and many smaller ones, interrupt the direct upward sequence to the north and south of Sarclet in the coast section. They fall into two systems—those with a north-north-westerly trend, and those with a west-south-westerly trend. To the north of Sarclet they throw down to the north-west and north-east respectively, while those to the south of Sarclet throw down to south-east or south-west ; but inland the faults cross one another and lead to a complicated group of faulted blocks arranged about Sarclet as if the latter acted as the centre of a dome-shaped anticline. By the proper interpretation of the effect of these faults it has been possible to trace a similar sequence in the beds of the coast section from Sarclet to Wick on the north and from Sarclet to Lybster on the south, and also to obtain some idea of the thicknesses of the different groups of strata. In face of the paucity of fossil fishes, except in the uppermost of these groups, the marked changes in lithological character, here as in

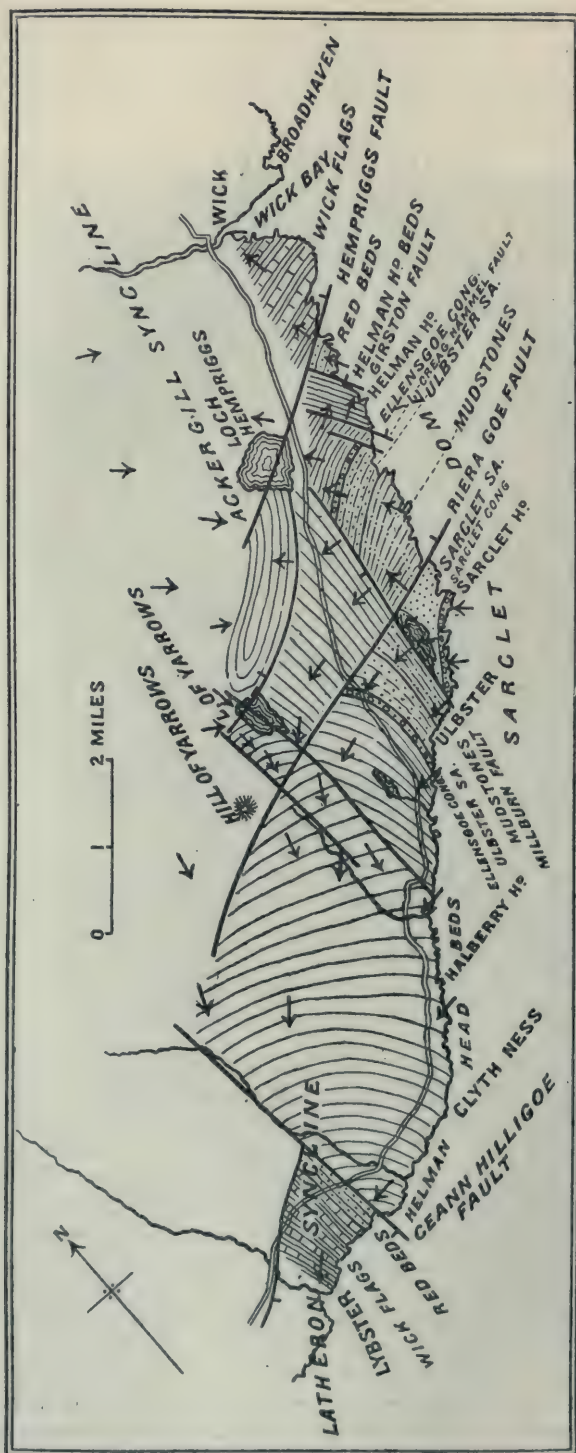


FIG. 6. Sketch Map showing the relations of the rock groups in the Sarclet Dome and parts of the Ackergill and Latheron Synclines in the Coastal District between Wick and Lybster.

the Berriedale and Dunbeath districts, have been of much value in following the upward succession.

THE SARCLET CONGLOMERATE.

This forms the mile and a quarter of rugged cliffs which advance seaward as a headland between Sarclet and the Stack of Ulbster (Fig. 8).

The coast-line for this distance is along the strike of the rocks, which to the north and south pass out to sea. The conglomerate is almost limited to the cliff, as its junction with the overlying Sarclet Sandstone closely follows the contours of the steep seaward slope overlooking the cliff-face. The base of the formation is not exposed, but a thickness of about three hundred feet of conglomerate is seen in the cliffs (Plate II.). The conglomerate dips steadily inland to the north-west, at angles which average 20°.

Its passage into the overlying sandstones is clearly exposed along the cliff-top, bands of the sandstone and conglomerate alternating. The main mass of the conglomerate shows little indication of bedding, and has the character of a deposit formed in the neighbourhood of steep

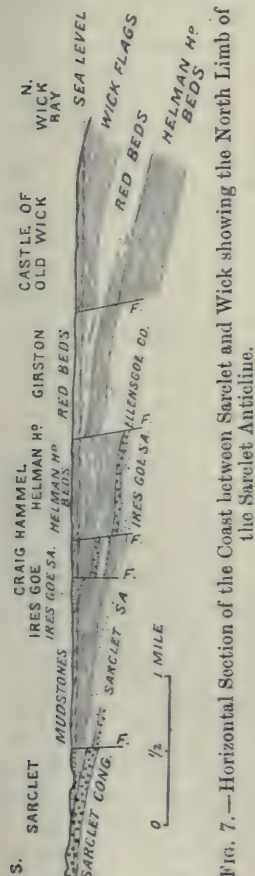


FIG. 7.—Horizontal Section of the Coast between Sarclet and Wick showing the North Limb of the Sarclet Anticline.

slopes. Original elevations of the floor of crystalline rocks have probably existed somewhere to the east of Sarclet, from which the angular fragments of the conglomerate were in all probability derived.

The Sarclet Conglomerate consists of large blocks and small fragments of granite, quartzite, and schist, packed closely together in a dark red arkose matrix. The fragments are for the most part angular, but usually have rounded corners, and some appear to be much water-worn. Small

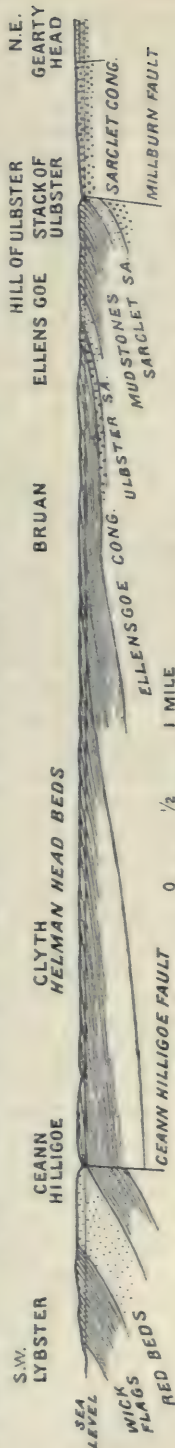


FIG. 8.—Horizontal Section of the Coast between Sarclet and Lybster showing the South Limb of the Sarclet Anticline.

pieces of reddish sandstone and black porphyritic basalt also occur. Where the cliff recedes into Sarclet Haven, in the direction of the dip of the rocks, the overlying sandstone rapidly succeeds the conglomerate and appears in the cliff. At its southern limits, the conglomerate is cut off by a north and south fault, the Millburn fault, which passes up the Millburn, and throws down the mudstones against the conglomerate (Fig. 8).

THE SARCLET SANDSTONE.

The Sarclet Sandstone has a larger outcrop than the conglomerate, but in the cliff section is limited to the half-mile from Sarclet Head northwards to Riera Goe (Fig. 7). In Sarclet Haven the sandstone forms a small syncline along a north-east axis, the general north-westerly dip being reversed for a short distance. This is accompanied by some disturbance of the rocks at the Battery north of the Haven, culminating in a crush having an east-north-east trend. Beyond this the rocks are still much twisted, but gradually resume a north-westerly dip, which continues with gentle angles to Riera Goe. Here the sandstones are abruptly truncated by an east-north-east fault, the Riera Goe fault, which throws down the overlying mudstones. The fault is a small one, as the sandstones are seen beneath the mudstones on the north side of the goe, but it probably increases rapidly inland.

The sandstone is cut out of the cliff section south of the Stack of Ulbster by the Millburn fault. On the east side of this fault, in the gully of the Millburn, the conglomerates pass up into the sandstones, and these again into the mudstones, and the whole thickness, 300 ft., of the sandstones is thus exposed. The outcrop of the sandstone widens farther to the north near Sarclet, but this is probably due to the gentler dip and the influence of the rucking and faulting north of the Haven.

The Sarclet Sandstone is, properly speaking, a thoroughly cemented arkose of dark or pale red colour. Bands of a gritty nature alternate with finer-grained bands, and emphasise the bedding.

THE ULBSTER AND RIERA GOE MUDSTONES.

The mudstones are represented in the coast section, both to the north and the south of the Sarclet Anticline, and extend fully a mile inland, but are divided into two outcrops by cross faults. The northern coast section extends from Riera Goe to Ires Goe, rather more than a mile. The beds dip at gentle angles, rarely exceeding 10° , to the north-north-west and north, throughout this distance, and show marked signs of disturbance at Ashy Goe, where they are turned up on end by a ruck. At Ires Goe, the beds terminate in a crush against the sandstones, which overlie them in the sequence, but the mudstones are seen beneath the sandstones on the northern side of the goe. Inland, the mudstones of the two outcrops are truncated by the Millburn and Riera Goe faults, which also cut out the overlying sandstones and conglomerate for nearly a mile, and let down a block of Helman Head Beds in the angle north-west of their point of intersection. The southern coast section of the mudstones begins at the Millburn fault, and extends westward seven hundred yards to Skeps Goe, south of the Mains of Ulbster. Here the Ulbster

Sandstone overlies them conformably in the cliff. The mudstones dip slightly north of west throughout this section, at first at an angle of 60° near the fault but gradually diminishing to 20° at Skeps Goe. With 30° as an average dip, the thickness of the group would be 800 ft., but this would not include some of the lowest beds cut out by the Millburn fault. If we disregard the ruck at Ashy Goe, the section north of Riera Goe, at an angle of 10° , would also give 800 ft. of beds. The mudstones are similar in character to those which lie between the Ousdale Arkose and the Badbea Breccia in the Berriedale area. They show the same red and pale green colours, and break up irregularly rather than along the well-marked places of bedding. They are also accompanied by pale pink calcareous fine-grained sandstones which weather with a "honeycombed" surface. Greenish beds are more frequent than in the Berriedale area, and the alternation of bands of bright colours makes the sea-cliffs of these rocks some of the most beautiful in Caithness.

THE ULBSTER AND IRES' GOE SANDSTONES.

The Millburn and Riera Goe faults, which divide the Ulbster and Riera Goe Mudstones into separate outcrops, interfere in like manner with overlying groups, the Ulbster Sandstone and the Ellens Goe Conglomerate. The Ulbster Sandstone overlies the mudstones at Skeps Goe to the south of Ulbster, and forms the sea-cliffs for more than half a mile south-west to Ellens Goe (Fig. 8), but for a part of this distance the coast-line nearly conforms with the strike of the rocks. From the sea the sandstone extends inland to form the Hill of Ulbster, to the north of which it is limited by the Riera Goe fault. The width of the outcrop near the sea, where the beds dip to the west at 20° , is 300 yds. It increases on the Hill of Ulbster to half a mile, but the dip there is only 5° . The thickness of the group is therefore about 300 ft.

On the northern side of the Sarclet Anticline the sandstone forms magnificent cliffs 200 ft. high from Ires Goe to a short distance south of Craig Hammel, where a north-west fault, the Craig Hammel fault, brings down the dark-coloured beds of the Helman Head group. The crush rock in this fault forms a prominent dyke-like feature on the face of the cliff. The sandstones in this section dip gently to the north-north-west, but, in the vicinity of the fault, swing round sharply to the north-east, and dip into it at angles of 35° .

About 250 yds. south of the fault, at Luishal Goe, the dark-coloured beds of the Helman Head group are let down in a trough between two faults about 50 yds. apart, and, seen from the sea, form a dark V-shaped patch in the face of the cliff, which contrasts strongly with the red colour of the sandstones.

The Ulbster and Ires Goe Sandstones resemble the Sarclet Sandstone in lithological characters, but are usually rather lighter in colour.

THE ELLENS GOE CONGLOMERATE.

The conglomerate at Ellens Goe is in three bands, 20 ft., 6 ft., and 12 ft. thick respectively, separated by a few feet of sandstones, like those on which the conglomerate lies. The outcrop of these conglomerate bands forms the Rowans, a striking prominence near

the edge of the cliff, north of Ellens Goe, and extends inland as a ridge, with a north and south trend. The conglomerate can be traced for about a mile and then passes under peat. About half a mile farther north, along the strike of the conglomerate, beds of the Helman Head group are exposed, and extend considerably farther to the east, so the conglomerate must be truncated, along with the lower groups, by the Riera Goe fault. At Ellens Goe, and also in smaller goes a short distance to the north and south, three small east and west faults dislocate the conglomerate bands which only reach sea-level at the point immediately north of the Head of Row.

The fault in Ellens Goe is particularly instructive since its small throw of 50 ft. displays, on the north side of the goe, the three bands overlying the Ulbster Sandstone, while, on the south side, the conglomerate bands follow the lower part of the cliff, and the Helman Head Beds are exposed above. The faults in the inlets to the north and south throw down to the north and afford excellent opportunities for noting the thickness of the conglomerate bands and their relation to the beds above and below them. The ridge of the Rowans lays bare the conglomerate to closer inspection. It dips to the west at angles of 15° or more, and consists entirely of somewhat angular fragments of schist and quartzite, closely packed in an arkose matrix. The absence of fragments of granite is noteworthy, since they are abundant in the Sarclet Conglomerate. The difference in the nature of the fragments in the two conglomerates is easily understood, as the ridge of crystalline rocks, from which the fragments forming the Sarclet Conglomerate were derived, must have been depressed at least 1400 ft. in the Old Red sediments before the Ellens Goe Conglomerate was formed. It is possible, however, that the fragments forming the Ellens Goe Conglomerate were not derived from the same direction as those of Sarclet.

North of the Sarclet Anticline the Ellens Goe Conglomerate is not exposed in the cliff section, since with the higher part of the Ires Goe Sandstone, it is cut out by the Craig Hammel fault. An exposure in the moss of Toftcarl, 500 ft. south-south-west of the cairn of the Hill of Toftcarl, is, however, sufficient to show that the band is represented. The rock is similar to the conglomerate at Ellens Goe, and dips to the north-north-west, conforming to the dip of the sandstones in the cliffs.

THE HELMAN HEAD AND CLYTH BEDS.

This group of rocks, unlike those already described, not only has an extensive coastal development, but extends over wide areas of the country inland. To the latter, however, it has been found impossible to assign definite boundaries on the map such as have been laid down for the underlying groups.

To the south of the Sarclet Anticline, the Clyth Beds range five miles along the coast, with a gentle westerly dip, from Ellens Goe to Ceann Hilligoe, one mile east of Lybster. In this coast section there is little indication of faulting. The section of Helman Head Beds north of the Sarclet Anticline is reduced to a mile of coast-line between the faults at Craig Hammel and Girston. The dip is at much steeper angles, but there must be a large part of the group absent through the influence of these faults and others.

It is in the Helman Head and Clyth Beds that the first well-marked records of the fish life of the period are found so far as the Caithness rocks are concerned, but the beds as a whole are very barren, and the few recognisable fragments of fossil fish that have been detected are all referred by Dr. Traquair to one genus, and they probably belong to one species *Thursius macrolepidotus*.

In the splendid sections of these beds at Helman Head, and in the cliffs near Clyth (Plate III.), a constantly repeated sequence, such as the following, is met with (given in ascending order) :—

1. Dark blue-grey, or almost black flagstones (Wick Flagstone type), with surfaces roughened by innumerable raised or indented markings, and covered with micaceous films ; passing up into—
2. Blue-black, finely micaceous stone-slates, which weather into pitch-black, papery shales. These effloresce with alum owing to the decomposition of much finely-disseminated pyrites. They are generally so calcareous about their middle as to form bands of hard blue-black impure limestone, splitting with difficulty into stone-slates, with smooth surfaces. It is in these limestones that the few fragments and scales of fish have been detected at Girston, Clyth, and several localities inland.
3. Fine-grained, pale blue-grey, slightly calcareous sandstones, usually in a few massive bands, and weathering with a pale pinkish or yellowish colour. The bedding is often disturbed by harder nodular masses, but these have no distinct outline.
4. The sandstone is usually succeeded by pale greenish mudstones which are often covered with sun-cracks. These greenish beds usually form a very small proportion of the rocks.
5. Dark flagstones as before.

The dark colour of the weathered surfaces of these rocks gives a sombre aspect to the cliffs which is only relieved on weathered faces by the pale banding due to the sandstones. The latter frequently form terraced features inland, as may be well seen on the Hill of Mid Clyth and Warehouse Hill, or stand up as small parallel escarpments over wide tracts of country where drift is thin or wanting, as about Bruan, Loch Watanan, and Thrumster. Along the cliff top small escarpments, consisting of the sandstone above and the black stone-slates below, alternate, at regular intervals, with the dip-slopes which are formed chiefly by the flags.

The lowest band of black stone-slates is seen in Ellens Goe, not many feet above the top of the Ellens Goe Conglomerate. But for several hundred feet from the base of the group, the flaggy beds are often greenish in colour, and even thin reddish bands occur, reminiscent of the Ulbster Mudstones. The lower beds are, however, easily distinguished from the strata of the mudstone group by the intercalation of the black stone-slates and by the repetitive character of the sequence. They strongly resemble and indeed are to be correlated with the Berriedale Sandstones and Flags of the areas farther south.

The yellow-weathering sandstones and the limestones are best developed in the middle of the group, and the black flags of the Wick Flagstone type usually take a larger share in the higher part of the series.

The highest beds are, however, nowhere exposed in the coast sections, and the passage from them into the overlying Red Beds has not been observed. At the small deserted harbour south of Ceann Hilligoe, the Helman Head Beds are truncated by a north and south

fault, the Ceann Hilligoe fault (Fig. 8). The crush rock in the line of fault stands up as a stack near the shore, and, a mile to the north, forms a line of prominent hillocks along the road leading to Camster and Watten. The downthrow of this fault in the coast section is to the west, and the plane of the fault fades distinctly in that direction.

The rocks of this group cover the whole country inland to the east of this fault, at least as far as the watershed. The numerous exposures generally exhibit dips to the south-west and south-south-west from Roster to Warehouse Hill. In the neighbourhood of this hill, numerous sections occur in the cliffs and gullies opened out along lines of crush, of which at least four extend over a mile in a north and south direction. Between Warehouse Hill and the Hill of Ulbster the beds swing round and dip to the west.

A feature which extends along the watershed from Whiteleen to the Cairns of Warehouse, and south of Loch Warehouse, probably marks a westward continuation of the Riera Goe fault. The throw of this fault to the north is probably sufficient to account for the extension of the rocks of the Helman Head group northwards across the watershed into the region of Loch of Yarrows. Apart from this fault, the continued southerly dip, from Warehouse Hill to Loch of Yarrows, would bring on beds belonging to the lower groups, but the base of the group, with the Ellens Goe Conglomerate, is nowhere met with, and the Helman Head Beds are evidently repeated by faulting parallel to this fault. There is another line of disturbance crossing Loch of Yarrows near its northern end, which in all probability marks another fault with a downthrow to the north. The great extent of the Helman Head Beds in the Thrumster and Yarrows districts is thus due to cross faults which throw down to the north and west, the chief of which are the Riera Goe and Millburn faults. But the Helman Head Beds of the Thrumster district also suffer repetition through their entering into the Ackergill Syncline. In the Warehouse district the beds dip to the south and south-west, but north-east of Loch of Yarrows the dip swings round to the south-east, and the beds, which in the Thrumster district are dipping to the west and north-west, are repeated in that direction. This north-westerly dip is the prevalent one between Thrumster and Wick, but so great is the influence of the Craig Hammel fault, and some subsidiary parallel lines of disturbance between Craig Hammel and Girston, that the beds in the coast section between these places are twisted round to dip to the north-east. The Craig Hammel fault can be traced inland, in a north-westerly direction, as far as Hempriggs House, by this marked difference in the direction of dip on either side of this line. The fault is probably a large one and cuts out much of the lower beds of the Helman Head group. At Girston the beds dip steeply into another fault which forms the northern limit of the Helman Head Beds in the coast section. There are probably over 2500 ft. of the Helman Head Beds.

THE RED BEDS OF GIRSTON AND HILLHEAD.

These beds occupy the cliff sections north-east of the Girston fault and west of the Ceann Hilligoe fault, but nowhere has their passage down into the Helman Head Beds been observed. The

PLATE III.



FLAGSTONE STACK CAPPED WITH BOULDER-CLAY, $1\frac{2}{3}$ miles east of Lybster.



rocks are red sandstones and greenish shales, and resemble the Berriedale Flags rather than the mudstones. The Red Beds between the faults at Girston and The Brough, for a long time indeed, were considered to be representatives of beds much lower in the series lying faulted up between the dark Wick Flags and Helman Head Beds. They here occupy about three quarters of a mile of the cliff section between Girston and The Brough. The Girston fault, which bounds them on the south, runs in a north-westerly direction south of the big stack, and enters the cliff obliquely, forming a great smash. The Helman Head Beds dip to the north-east steeply towards this fault, but are slightly inverted in its immediate vicinity. This at first suggests that the downthrow may be to the south-west. The Red Beds are, however, dipping greatly to the north-west, and it is probable that the rucking near the fault line in the Helman Head Beds is due to flanking slips throwing in an opposite direction to the main fault. The presence of similar red beds south of the Ceann Hilligoe fault, on the south side of the Sarclet Anticline, proves that the Red Beds of Girston and Hillhead normally overlie the Helman Head Beds, and that the faults at Girston and Ceann Hilligoe throw down to the north-east and west respectively. The Ceann Hilligoe fault has a well-marked hade to the west, indicating a downthrow in that direction, and the red rocks, to the west of the fault, appear to pass up directly into the fish-bearing flags of Lybster, which are in every way identical with those of Wick. There appear to be about 1000 ft. of the Red Beds in the coast section at Hillhead. They can be traced inland for nearly a mile. To the north of this, they are suddenly replaced by dark beds of the Helman Head type, and are therefore, in all probability, cut off by a north-east fault, an extension of the great Latheron fault, which in the Forse district has a large downthrow to the south-east. In the Girston or northern district, the Red Beds can only crop out over a small triangular area near the coast section. They are limited on the north by the Hempriggs fault which enters the cliff in the inlet north of the stack called The Brough. This fault throws down the Wick Flags to the north and probably extends a long distance inland in a south-westerly direction.

THE WICK AND LYBSTER FLAGS.

The Wick Flags occupy the coast section from the Hempriggs fault northwards to Broad Haven (Fig. 7). They dip for the most part to the north-west at angles of 10° to 20° . In the Latheron Syncline the same beds form the coast section for about three quarters of a mile east of Lybster Harbour (Fig. 8). Here, however, the beds are dipping at high angles to the south-west. There are probably 2000 ft. of beds represented.

The Wick Flags in part resemble the Helman Head Beds, but differ from them in the following particulars. The coarse dark flagstones (Wick Flagstone type) are similar to those of the Helman Head Beds, but have a much greater relative development. The bands of sandstone and dark smooth stone-slates are in consequence repeated with less frequency. The sandstones are thinner, and, from the great development of the flagstones, are quite subordinate to them. The limestone bands in the dark stone-slates are rather purer and contain

abundant fish remains, including *Thursius macrolepidotus* and *Dipterus Valenciennesii*. These fish-bearing beds in the coast section between Wick and the Old Castle of Wick have been repeatedly searched for fossil fish since the time of C. W. Peach. In the Lybster section fish remains are abundant in limestones on the promontory east of Skaill Harbour and also in the Reisgill Burn.

The lithological differences between the Wick Flags, the Helman Head Beds, and the Papigoe Beds, which overlie the Wick Flags, are quite apparent in the cliff sections, but in the limited exposures inland, mostly in quarries, there is great difficulty, owing to absence of fish remains, in distinguishing them from each other, and the laying down of boundary lines separating these groups inland has not been attempted. There are good reasons, moreover, for believing that the country round Wick is traversed by many faults, which, owing to the scarcity of large exposures, it has been found impossible to trace.

At Lybster the Wick Flags probably extend inland only as far as the Latheron fault. To the north of this fault the Helman Head Beds have a wide distribution northwards to the watershed and westwards to near Dunbeath.

Correlation of the Rocks of the Sarclet Anticline with those of the Berriedale Outlier and the Braemore and Dunbeath Districts.

It has already been pointed out that the fringing breccias and basement conglomerates of the Berriedale and Morven districts form local bases at varying horizons, and there can be little doubt that the Sarclet Conglomerate is of the same nature. The Sarclet Sandstone is probably also a fringing deposit like the arkoses below the mudstone group of Ousdale.

The mudstones on either side of the Sarclet Anticline exactly resemble the Ousdale Mudstones, and differ lithologically from any other beds in Caithness. It will be noted that the mudstones are, if anything, thicker near Sarclet than in the Ousdale district. They are a true basin deposit and not merely fringing deposits such as the breccias and arkoses. The Ellens Goe Conglomerate lies on the same horizon as the Badbea Breccia and Morven Conglomerates. The unconformity at the base of the Badbea Breccia and the Achnahavish conglomerate, was probably due to crustal disturbance, which led to a widespread greater erosion, with the formation of extensive gravel fans, but only locally caused erosion of deposits already formed. The lower part of the Helman Head Beds must therefore represent the Berriedale sandstones, while rather higher beds in this group would represent the Berriedale Flags.

The correlation of the Sarclet, Dunbeath, Braemore, Morven, and Berriedale Districts is given below in tabular form :—

BERRIEDALE.	MORVEN.	BRAEMORE AND DUNBEATH.	SARCLET.
<i>Wanting through denudation.</i>			Wick Flags. Red Beds.
Berriedale Flags. Berriedale Sand- stones.	<i>Wanting through denudation.</i>	Berriedale Flags. Berriedale Sand- stones.	Helman Head Beds.
Badbea Breccia.	Conglomerates and Sandstones of Morven, Smean, Maiden Pap, etc.	Conglomerates of Beinn nan Coireag, Achnahavish, Wag Hill, etc.	Ellens Goe Conglomerate. Ulbster Sandstone.
Ousdale Mudstones.	Braemore Mudstones.	Braemore Mudstones.	Ulbster Mudstones.
Langwell Conglomerates.	Basal deposits, sometimes <i>wanting</i> , rarely seen.	Braemore Conglomerates.	Sarclet Sandstone. Sarclet Conglomerate.

C. B. C.

CHAPTER V.

THE LATHERON SYNCLINE.

BASIN OF THE REISGILL BURN AND DUNBEATH WATER.

STRATA similar to the foregoing are found for several miles inland, to the north of Janetstown, and west of the line of the great Latheron fault. Grey sandstones are predominant; they are slightly calcareous and often show a peculiar gnarled contortion of their bedding planes. The intervening bands of rough dark-weathering flagstone not infrequently include thin layers (6 ins. to 2 ft.) of dark, smooth-splitting "limestone." Fish remains, all of *Thursius* type, are invariably found in these limestones, and do not occur elsewhere. The whole series may be referred to the Helman Head and Clyth Beds, belonging to the Lower division of the Caithness Flagstones.

The strata are arranged in a gentle syncline around Ben-a-chielt; the fold widens out to the north-east, and a subsidiary syncline is developed around Ballharn Hill.

The sandstones form prominent escarpments appearing in innumerable step-like forms around the flanks of the Hill of Leodebest, Ben-a-chielt, Stemster Hill, and the Hill of Rangag; further east, they reappear in the other side of the syncline near the Grey Cairns of Camster.

Characteristic exposures of these beds are seen on the shores of Loch Stemster and east of the road near Achavanich. From this region down to the Latheron fault the drift cover is so thin that countless small natural exposures of these strata can be found, although none of them can compare with those seen on the coast at Janetstown or to the north-east of Lybster.

The "limestone" bands, although highly calcareous, are not sufficiently so to be of economic value. The fish remains found in these beds are usually rare and in the form of detached scales or head plates. The two best localities are (1) in the streamlet on the hillside about a quarter of a mile north-east of the shore of Loch Stemster, and (2) in the small roadside quarry at Achow.

The "limestone" mapped west of Latheron is believed to be on a slightly higher horizon than that at Knockinnon.

Few of the faults seen in this area can be traced for any great distance. One of them can be followed as a line of crush from Latheron Hospital to Brachungie, and belongs to a system of north-north-west faults and joints common in this district, and well seen on the coast south of Janetstown. In the crush line there is, in one part, a development of limonite which occurs in such quantity that the croft here is known as "Red Rock."

A smaller fault, belonging to the same system, lies about a mile farther north; limonite is found here also. There is a good example of a normal fault north of Stemster Hill; this disturbance runs north-east and displaces the "limestone" bands.

Isolated outcrops of crush breccia can be seen at the Hill of Bigous and in the streamlets to the north and north-east, but it is impossible to say whether they are true faults or only lines of crush.

The steep dip and rapidly varying strike of much of the strata seen west and south-west of Osclay, also seem to indicate the presence of a line of disturbance.

The thickness of strata of Helman Head type, measured by projection from Reisgill Bridge (half a mile west of Lybster), to the core of the Ben-a-chielt syncline must be little short of 2000 ft. On the south-east side of the syncline, the total thickness of strata (already given in part), from the shore at Janetstown up to the crest of the Hill of Leodebest, is about 800 ft.

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The low moorlands that stretch from the Cnoc an Earrannaiche watershed northwards to Watten, are floored by higher beds, belonging to the Wick Group. The small sections seen in the streams that meander through this peat-covered waste, generally show rough dark-coloured flags with occasional beds of "limestone" similar to those noticed farther south in the Helman Head Beds. Here, again, the few fish remains found are confined to the "limestone" bands. The most accessible fossil localities are (1) at the bend in the Strath Burn, rather over a quarter of a mile south-west of Strath, and (2) in the Burn of Acharole at The Clow, nearly half a mile south-west of Scouthal; the Strath section is disturbed by faulting, but fossils are more plentiful than at The Clow.

The faults found in this area are few, the most important ones being the two branches of the Brough fault, *i.e.* the Camster and Halsary faults. The former is well seen by the roadside above Bowlangla, where the fault breccia is conspicuous; the continuation of this disturbance is indicated farther south by the abrupt upturning of the Helman Head sandstones, near the Grey Cairns of Camster, and by the roadside near Roster.

The Halsary fault is visible at the branching of the Acharole Burn, three-quarters of a mile above Shielton. Farther to the south and south-west, its direction can only be inferred by the tilting of the strata past Halsary, and up the valley of the Little River and Loch Rangag.

COAST SECTION—LYBSTER TO LATHERON.

On the west side of Lybster Bay there is some disturbance of the strata, due to the line of crush seen inland down the Reisgill Burn, south of the main road. Any actual displacement so caused, must be of small amount, for farther south there is a continuous sequence of typical Wick Flags (similar to those seen north of the Bay) for half a mile beyond Leac Gallain. These beds are capped by a hard "limestone" band, barren of fossils, which is seen on the cliff some 350 yds. east of Achastleshore.

Farther south, dark-weathering flags are again seen, and on the headland at Achastleshore itself, another "limestone" band is found. This bed is also about 18 ins. thick, and is of the same lithological

type as those seen above the Wick Flags on the north side of the Sarclet Anticline at Papigoe. The "limestone" is very hard, and weathers in very pale blue and ochreous colours; *Coccosteus* is found in some abundance. As also at Papigoe this is the first record of the genus in the upward succession from the basement beds at Sarclet. Well-preserved specimens of *Thursius macrolepidotus* also occur, but are not very common.

Farther west, the overlying flags are dark and rough, and there are intercalated beds of hard yellowish sandstone. Another "limestone" band is found on the steep rocky slope 500 yds. west of the mouth of the Achastle Burn; this bed is dark grey, like those in the Wick and Helman Head Beds, but *Coccosteus* is present in some abundance. The "limestone" is succeeded by a flagstone series of a remarkably thin-bedded character. These flags are usually dark-weathering, but certain bands have a pale blue or ochreous colour, and thin lenticles of creamy "calmstone" are not uncommon. They are probably equivalent to the Noss Head Flags, seen north of Wick, to which they show a remarkable resemblance.

Overlying the thin-bedded flagstones, on the point known as Robbery Head, one-third of a mile north-east of Port na Muic, a band of "limestone" accompanied by papery slates has been quarried to some extent. This "limestone" is again of the "Papigoe" type, and contains *Coccosteus* fragments in some abundance; *Acanthodes* has also been found.

The slates associated with this bed weather dull yellowish-grey or blue; those some distance above the "limestone" weather in brighter colours and can be seen at the foot of the cliff a few score yards west of the head. The cliffs then suddenly rise sheer up from the water, and on the extreme edge of the precipitous face there is a band of smooth splitting grey "limestone" which runs down to a cave at sea-level. This limestone exactly resembles that at Achanarras, and from this bed (the Niandt "limestone"), typical representatives of the peculiar Achanarras fauna * have been collected by Mr. Tait.

For a short distance farther west, as far as Port na Muic, access to the cliffs is only possible by boat. The flagstones above the Niandt "limestone" weather pale blue, green, and ochre, although the colours are obscured by staining on the joints that form the cliff face. One or two bands of reddish-yellow sandstone also occur.

At Port na Muic a south-westerly fault throws down strata on the north side, but apparently to no great extent. Farther south excellent sections can be seen in the low broken cliffs. Up to the mouth of the Latheron Burn all the flagstones agree in every way with those typical of the Thurso Group; they are, when fresh, leaden grey in colour, and weather pale blue, yellow, or cream. Scattered fish scales and plates of *Coccosteus* are very common, and bituminous nodules characterise certain bands. In addition there are several beds of false-bedded and concretionary red and yellow sandstone, exactly like the sandstones intercalated with blue flags at Ackergill (Sinclair's

* The fishes collected were:—*Palæospondylus gunni* Traq., *Mesacanthus* sp. *Cheiracanthus* sp., *Pterichthys* Milleri Ag., *P. productus* Ag. *Dipterus Valenciennesii* Sedgw. and Murch., *Glyptolepis paucidens* (Ag.), *Osteolepis macrolepidotus*? Ag.

Bay). The coast section hereabouts is obscured by several minor crush lines, culminating in a large fault running across the mouth of the Latheron Burn. This dislocation is marked by a considerable development of crush breccia; the downthrow is to the east, probably about 1000 ft., for the strata on the upthrow side are dark-weathering and in strong contrast to the Thurso type previously seen. These dark flagstones probably belong to the upper part of the Lower group, as *Coccosteus* is found in some abundance in "limestone" bands south of the burn; these beds strike along the coast for about half a mile farther. The *Coccosteus* beds are then cut off by the main line of the great Latheron fault, giving rise to a crush breccia several yards across, which is seen on the low cliffs one third of a mile north-east of Janetstown Harbour.

The dislocation caused by this fault must be enormous; probably 6000 ft. is a conservative estimate, for the *Coccosteus*-bearing beds are brought against strata low down in the Helman Head Beds.

A few supplementary notes are advisable with regard to the foregoing description of the Lybster-Latheron coast, for the section affords data of the first importance in elucidating certain points in the stratigraphy of the Caithness Flagstones.

The lower part of the section, from Lybster up to Achastleshore, compares very well with the succession seen north of Wick on the other side of the Sarclet Anticline. In both cases dark flags of the Wick type are succeeded by strata containing *Coccosteus*-bearing "limestones" of a peculiar lithological type (Papigoe "limestones"). Over these beds thin-bedded flags are found, so closely resembling the Noss Head Flags that an actual correlation between the two can be suggested. The point is of interest, because at Noss, owing to faulting, it can only be said that the flags are in some indeterminate position above the Papigoe and Castle Sinclair Beds; the evidence on the Latheron coast suggests that they immediately succeed the Castle Sinclair Beds, and the faulting between the two series at Noss Head is of small amount.

The lithological identity of the strata around the Niantt "limestone" and the "limestone" at Achanarras is remarkable considering the distance between the two localities. Not only are the two "limestones" of a similar character, but the agreement extends to the papery slates and the Robbery Head "limestone," both of which are also found in a similar position near Achanarras.

The fact that the overlying strata are of such a pronounced Thurso type confirms the correlation in a striking manner, and supports the conclusion that the Thurso Group is in normal superposition on the Wick or Lower Flagstones—an opinion arrived at elsewhere by other lines of evidence.

The crush breccia of the great Latheron fault is visible not only on the coast section, but again about a quarter of a mile above the mouth of the Latheron Burn, and in the Reisgill Burn at the bend just below the main road.

It is natural to expect that a dislocation of such magnitude would be accompanied by many minor branching faults, and these are to be found in the numerous crushes and lines of disturbance that break up the coast section west of Port na Muic.

R. G. C.

CHAPTER VI:

THE NORTH-EAST OF CAITHNESS.

COAST SECTION FROM WICK TO FRESWICK.

THE coast sections between Wick and Ackergill are remarkable for the number of "rucks" and crushes which traverse the rocks mainly in two directions, namely those of strike and dip of the strata. Some of these are of great width as, for example, that which have been excavated by the sea to form Broad Haven. In the "rucks" the beds are highly inclined or turned on end between parallel vertical joint planes, while the beds on either side often show little relative displacement. The crushes are generally narrower than the "rucks," and consist of a breccia of fragments of the flagstones in a matrix of fine cemented debris and crystalline calcite. They sometimes resist erosion more than the neighbouring strata, and at North Head, Wick, stand up above the general level of the shore reefs. Here the displacement of the strata along the crush lines is at most a few feet. In many of the rucks and crushes, apart from beds included in the ruck, there appears to be no real displacement. In others there are probably big faults, but it is often difficult to determine even the direction of throw, as the plane of dislocation is vertical and the rocks on either side show little disturbance. On the vertical walls of these crushes slickensides may sometimes be seen, which are in some cases vertical while in others they are more or less inclined to the horizontal, so we probably have to deal not only with vertical but also with horizontal movements or wrenches.

In spite of prolonged search the position of the band containing the Achanarras fish-fauna has not been found in the coast section north of the Sarclet Anticline. The horizon characterised by this fauna should occur in the sequence of beds forming the coast line between Wick and Ackergill, but from the want of success in the search we are driven to the conclusion that it is either faulted out of the coast section, or may not have been deposited as a limestone in this part of the basin. From its position in the lithological sequence south of Lybster, there is reason for thinking that the "Achanarras band" may be faulted out between Castle Sinclair and the Ackergill Lifeboat Station by the wrench fault which separates the Noss Beds and the Ackergill Beds.

The Wick Flags have already been stated to dip to the north-west in the coast section as far north as Broad Haven. These are followed in the coast section to the north by the following lithological groups:

3. John o' Groat's Sandstone Group.
2. Thurso Flagstone { Mey Beds (local development).
Group. { Ackergill Beds (local development).

[? Position of the "Achanarras Band."]

- | | | |
|------------------|---|--|
| 1. Passage Beds. | { | Noss Beds.
Castle Sinclair Flags.
Field Beds.
Papigoe Beds. |
|------------------|---|--|

The beds overlying the Wick Flagstone Group are conveniently grouped as Passage Beds. Lithologically the Papigoe and Field Beds have resemblances to both the Wick and the Thurso Flagstone Groups. The Castle Sinclair Flags, on the other hand, are practically indistinguishable from the Lybster Flags, and with the Noss Beds are lithologically of the type of the Thurso Flagstone Group. The Passage Beds contain *Coccosteus decipiens*, a fossil not found in the beds beneath, but some of the fossil fish of the Thurso Flagstone Group as *Thursius pholidotus*, *Coccosteus minor*, *Homosteus Milleri*, and *Glyptolepis paucidens* have not been detected in them.

THE PAPIGOE BEDS.

In Otter Goe, on the north side of Broad Haven, the beds are steeply inclined in a "ruck" limited on its north side by a fault. Beyond the fault the dip changes abruptly to the north-north-west, and a group of rocks of different lithological character from the Wick Flags is encountered.

These, the Papigoe Beds, extend northward in ascending sequence as far as Staxigoe, the dip of the rocks gradually changing in direction from north-north-west to north, and varying in inclination from 25° to 10°. The section is considerably broken by crushes, but if we neglect their influence, the rocks exposed would amount to more than 1000 ft. in thickness.

The Papigoe Beds show constant repetitions of a very definite sequence of strata like the Helman Head Beds and Wick Flags, and consist of pale greenish flagstones and mudstones, fine-grained sandstones, dark blue-black stone-slates and flags, and pale weathering limestones, but limestone bands are the most noticeable members of the series, since they are better developed and purer than in any other of the lithological groups of the Caithness Flags. They contain *Thursius macrolepidotus*, *Dipterus Valenciennesii*, and *Coccosteus decipiens*.

It is in the Papigoe Beds that the pale-weathering bluish-green flags, so prevalent higher up in the Caithness sequence, are first encountered in the upward succession. The dark coarse flags of the Wick type are much reduced or absent. Lithologically these beds are passage beds from the Lower or Wick type to the Upper or Thurso type of flagstones, and it is in them, moreover, that *Coccosteus* occurs for the first time. From the sudden change in the character of the beds, there is little doubt that the Papigoe Beds are faulted down against the Wick Flags at Otter Goe, but there is no direct evidence as to the amount of throw of the fault. Beds of the Papigoe type overlie the Wick Flags in the Latheron section, as pointed out in the last chapter, but from the vertical nature of the cliffs there is difficulty in finding the point where the passage from the beds of the Wick type takes place.

A short distance north of Papigoe, between Papigoe and Elsay Goe, there is a dark massive band intercalated in the section. The band is 50 ft. thick, and in its type of weathering suggests a basaltic rock. It is very hard and heavy, and rings under the hammer. The bedding planes are, moreover, very indistinct, but the rock effervesces with acid and proves, on microscopic examination, to be a very fine-grained sandstone rich in iron oxides and lime. A band of a similar nature, but probably at a higher horizon, occurs in the Latheron section near the Robbery Head limestone.

THE FIELD BEDS.

Beyond Staxigoe the limestones and black stone-slates are absent from the coast section, and the beds consist chiefly of pale-weathering, calcareous flags, greenish mudstones, and a few bands of sandstone. The dip is continuously to the north at angles of 10° to 15° , but crushes are so numerous that beds might easily be omitted through faulting. The rocks resemble the Castle Sinclair Flags, but there is no very distinctive lithological character in the beds till we approach Field. No fossils have been obtained from these beds, which must amount in thickness to about 250 ft. At Field these beds are followed by a group of rocks of strong lithological character known as the Field Beds.

The Field Beds extend along the coast for 600 yds. north of Field. They dip to the north-north-east at angles averaging 10° , and there appear to be between 400 and 500 ft. of strata. They consist of three groups of dissimilar strata, which form a definite sequence repeated five times in the coast section. These groups are (1) sandstones, (2) greenish white mudstones with sun-cracks, and (3) black, slightly calcareous, and very bituminous stone-slates containing fish remains.* There is locally a marked east and west slickensiding on the bedding planes, and the thin mudstone bands have a puckered appearance. A low-angled cleavage, almost amounting to thrusting, is common, and fades to the east. The sandstones are lenticular, thickening and thinning out to a marked extent. They form bands 6 ins. to 10 ft. thick, interleaved with hard pale-green mudstone. The beds of sandstone in each group become gradually thinner upwards, and eventually give way to greenish white mudstones with large sun-cracks. The thicker sandstone beds show contorted bedding, the thinner bands are ripple-marked. The sun-cracked beds are in turn succeeded by the black stone-slates which contain *Coccosteus decipiens*, *Dipterus Valenciennesii*, and *Thursius*. These black beds are micaceous and resemble the black stone-slates of the Wick and Helman Head Beds, but are more bituminous.

THE CASTLE SINCLAIR FLAGS.

These have a wide development in the coast line to the south and west of Noss Head. They consist of alternations of rather thick bedded, pale-weathering, greenish and bluish-grey flagstones, rather soft and calcareous; some pale greenish mudstones with sun-cracks; and darker bluish-grey, smooth-bedded calcareous flags with *Coccosteus*

* See p. 92.

decipiens, *Dipterus Valenciennesii*, and *Thursius*. The different beds vary little in colour or fineness of grain, and form cliffs with a very homogeneous appearance. There are about 400 ft. of the Castle Sinclair Flags exposed in the coast section.

The beds forming Noss Head are separated from the Castle Sinclair Flags by a fault, the Noss Head fault, which passes from Scholl, across the headland, to Moneygoe, east of Castle Girnigoe. It hades slightly to the north-east, and throws down in that direction. South of this fault, there is a band of unusual character in the Castle Sinclair Flags. This band, which may for convenience be called the "Castle Haven Band," differs from the other beds by its total absence of bedding laminae, although it apparently consists of the same fine grey clay as the flagstones. It is of value in connecting the sections in the Castle Sinclair Flags on the south and west of Noss Head, since it reappears on the north coast in the Haven of Castle Girnigoe. Two faults with drops of a few feet are also proved in the goes at the Castle by means of this band.

Near the Noss Head fault the beds dip to the east of north, but, as we pass westward along the coast, the strike gradually swings round, and the beds first dip to the north and then to the north-west and west-north-west. Along this coast-line the Castle Haven Band can be followed for about a mile, and forms the base of the stacks outside the cliff.

THE NOSS BEDS.

The strata forming Noss Head (Plate V., 2) for the most part dip to the north-east at angles of 5° to 20° . From their strongly-marked litho-

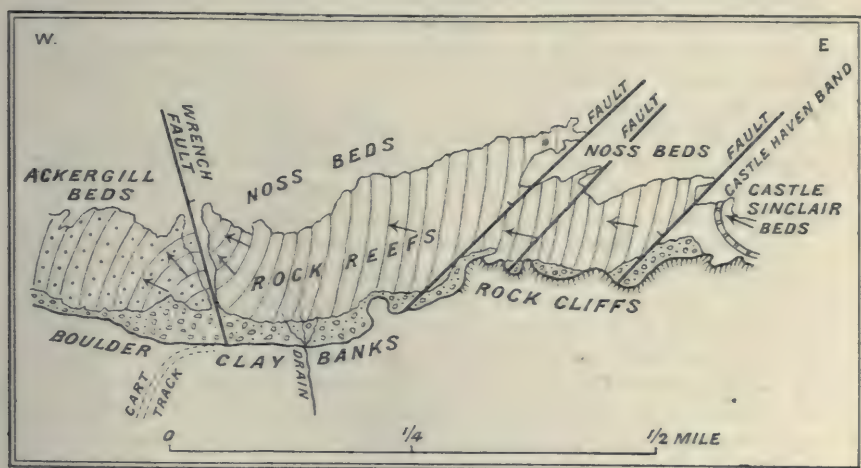


FIG. 9.—Sketch Map of part of the Coast-line between Ackergill and Castle Girnigoe.

logical characters they are separated as the Noss Beds. Their peculiarity lies in a very rapid alternation of thin beds of very unlike character. Thin bands of rippled sandstones, pale greenish mudstones, thin lenticular black limestones weathering yellow, and thin black flags follow one another in quick succession. The flags have small, sandy inclusions which stand out on weathered surfaces. The only fish

remains as yet found at Noss Head are fragments of *Coccosteus decipiens*.

About 300 yds. westwards along the coast from Castle Girnigoe, three faults follow one another closely with a north-east trend (Fig. 9). They form gaps in the cliff, and the rocks are much reddened. The rocks beyond the first of those faults are like those of Noss Head, and rocks of this type dipping to the west extend beyond the other faults in the shore section as far as a fourth fault. This traverses the shore reefs in a north-north-westerly direction, and is situated a few yards beyond the point where the cliffs give way to the boulder-clay slope. The smash indicates a line of lateral wrench, since the beds on either side are deflected towards it in opposite directions. The sketch map shows the faults and relations of the different groups of beds in this part of the coast-line (Fig. 9).

The deflection of the strata near the wrench fault indicates a relative movement to the south along its east side. Ackergill Beds occur on the west side of the wrench, but their relation to the Noss Beds is not indicated. The former contain *Glyptolepis paucidens* and *Coccosteus minor*, fossils abundant elsewhere in the Thurso Flagstone Group but apparently absent from the Noss Beds and the Castle Sinclair Flags which underlie them. It is therefore probable that the fault at this point is a large one, and cuts out the basal members of the Thurso Flagstone Group with the horizon of the "Achanarras Band."

ACKERGILL BEDS AND THURSO FLAGS.

West of the wrench fault the Ackergill Beds form reefs between tide marks to a point about three-quarters of a mile beyond Ackergill Tower, where the rocks disappear beneath the sand.

The coast section of those beds is interrupted by several rucks, some of which indicate lines of fault. The most conspicuous of these is near the Lifeboat Station, and occupies the centre of the syncline in which the beds are arranged. In the ruck the beds are turned on end and strike north and south. To the east of it the beds are dipping to the west; on its west side they dip to the east as far as the coast section continues.

The Ackergill Beds consist in large measure of sandstones, which are false-bedded and coarser in grain than any of the sandstones of the Field, Wick, or Helman Head groups. They rather resemble the sandstones of the John o' Groat's group, but vary much in colour from grey and brown to yellow and red. They often include fragments of fossil plants, and thin layers of fine grit may be detected in them, a rare condition in association with flagstones. With the sandstones are greenish-grey flags and sun-cracked beds, similar to those of the Castle Sinclair Flags, also curious conglomerate-like bands, or "nodule beds," such as are met with in the Mey Beds. Besides these there are bands of hard, black, bituminous shale with small fragments of fossil fish and plants. The fossil fish have been referred to *Glyptolepis paucidens*, *Dipterus Valenciennesii*, and *Coccosteus minor*, the last-named being found also in the Mey Beds.

The bituminous bands are often contorted in a way suggestive of the curly oil-shales of Midlothian, and have yielded an inflammable gas on distillation. The best exposures of the bituminous shales in the

coast section lie opposite Ackergill Tower. Similar bands of black bituminous shale are exposed on the north coast near Harrow, where they occupy a horizon low down in the Mey Beds.

The "nodule beds" consist of fragments of sandstone in a mud-stone matrix, and will be further described when the Mey Beds come to be considered.

The Ackergill Beds have indeed certain remarkable points of lithological resemblance to some parts of the Mey Beds, and this likeness is strengthened from the palæontological side by the occurrence in both of the little fish *Coccosteus minor*. There is, perhaps, a thickness of 500 to 600 ft. in the Ackergill Section, but the beds are repeated by their synclinal arrangement, and also by faulting west of Ackergill Tower. Beds of the Ackergill type are found inland only as far south as Upper Ackergill, but the synclinal arrangement can be traced for six miles into the Thrumster district, as has already been pointed out. The beds inland, in the districts of Killimster and Reiss, show the same easterly dip as the beds forming the western limb of the syncline in the coast section. It is, however, difficult to make sure what horizon these beds belong to in the small sections exposed in scattered quarries. A band of black bituminous shale like that at Ackergill has been quarried at Killimster. It is locally called "black man" and has yielded inflammable gas on distillation. Numerous plant remains, and the little crustacean *Estheria membranacea*, have also been obtained from quarries in this district.

To the north of the great stretch of sand in Sinclair's Bay, beds of the Ackergill type are again met with in the coast section between Rough of Stain and Keiss Castle. The beds are gently rolling, but, for the most part, dip at low angles to the east and south-east, proving an extension of the western limb of the Ackergill Syncline farther to the north. The strata are like those at Ackergill and contain the same fossil fishes, except that *Coccosteus minor* has not been detected. For several miles north of Keiss, the strike of the rocks is almost parallel with the coast line, and the beds dip gently seaward, forming low cliffs and coastal ledges. Near Keiss House there are several east and west lines of disturbance, which may indicate faults, but the beds of Ackergill type seem to die out laterally in a northerly direction. The bands of sandstone are lenticular, and gradually give place to flagstones along the strike of the beds. It is, therefore, probable that the Ackergill Beds are of local significance only.

In the coast section north of Keiss, flagstones are met with as far as Ness Head. The flags dip to the east at gentle angles, and the section is easily examined from the rock platforms beneath the cliff at least as far north as Nybster. Quarries along the cliff top and others near the coast have yielded *Thursius pholidotus*, *Homosteus Milleri*, *Glyptolepis paucidens*, and *Estheria membranacea*. At the fishing station at Nybster a well-marked thrust plane traverses the cliff and shore reefs. It fades to the east at low angles. The movement along it is, however, probably only a few feet.

In the reefs seaward of Bucholly Castle, a ruck runs parallel with the coast-line and turns the beds on end with a north and south strike. Immediately north of the Castle an east and west fault cuts the cliff and forms the Castle Goe. This fault shifts the line of

ruck farther west on its north side, so that it enters the cliff on the north side of the goe.

On the south side of Freswick Bay, underlying the flags of Ness Head, beds of the Ackergill type are again met with. They dip to the east at angles of 10° to 15° , and form the reefs beneath the cliff. They display the same "nodule beds" and bands of black bituminous shales as at Ackergill and Reiss, and can be followed westward in the reefs in descending sequence until they pass under the sand backing the bay.

COAST SECTION—FRESWICK TO DUNNET.

On the north side of Freswick Bay the low cliffs are formed of friable yellow and red sandstones belonging to the John o' Groat's Sandstones, the highest group in the Caithness Flagstone Series. The rocks dip to the west-north-west, or precisely in the opposite direction to the dip of the Ackergill Beds on the south side of the Bay. There is, therefore, a fault, with a more or less lateral wrench beneath the sand in Freswick Bay, which has an east and west trend and a large downthrow to the north.

THURSO FLAGS OF THE HAM ANTICLINE.

In order to resume our description of the beds in as nearly as possible an upward succession, it will be necessary to transfer our attention to the north coast at Ham, where the lowest beds in this part of the coast section are brought up on the back of a north-and-south anticlinal fold. Along the coast-line west of Ham, as far as the fault at The Brough, which limits the Upper Old Red Sandstone of Dunnet Head, the beds are dipping to the west-north-west at angles of 10° to 30° . For a short distance near the fault, the dip is, however, very irregular, as the beds incline to the north, east, and south, changes in direction due to flanking dislocations, which appear in the main to throw down to east. There are also several north-and-south rucks in the beds farther east. They may indicate faults, but there is little difference on either side of them in the character of the beds, or in the direction of dip. These beds are lithologically of the Thurso Flag type, pale-weathering and somewhat calcareous, but only fragments of *Cocosteus* have been reported from them.

At Ham Berry the dip swings round to the north and north-east on the back of the anticline, and to the east of the harbour becomes due east as far as the promontory called the Kirk o' Tang. The strata are like those west of Ham, and dip at angles of 10° to 20° . At the Kirk o' Tang, sandstone bands, somewhat resembling those of the Ackergill Beds, are intercalated in the flagstones, and the dip inclines to the north-east. Between this and Scarfiskerry Point the beds are dislocated by well-marked faults running in a north-westerly direction. One forms the ruck in the haven at Scarfiskerry, and from this to Ruthy Goe, 200 yds. farther west, the beds are arranged as a small syncline let down between the two faults.

At Scarfiskerry Point the beds resume their north-easterly dip at angles of 30° to 40° , and higher beds succeed rapidly in an easterly direction in the coast section. Some of the beds near Scarfiskerry

have a strong lithological resemblance to the Noss Head Beds, but the bulk of the rocks are distinctly of the Thurso Flag type.

At the Mill of Mey the dip is about 20° to the north-north-east. Large fragments of *Glyptolepis paucidens* occur in a band near the Mill. In Harrow Bay, farther east, there is a band of black bituminous shale like those in the Ackergill Beds. Another exposure of this band occurs in a quarry near the Berriedale Arms, about one mile inland. It was from this locality that the shale was taken for the distillation analysis quoted by Murchison.*

MEY BEDS.

From Harrow to St. John's Point and Scotland's Haven, there are local changes in the character of the rocks forming the coast section. They consist of pale blue or buff-weathering calcareous flagstones with fish remains, pale greenish-white mudstones with large sun-cracks, and bands of sandstone. The flagstones and mudstones are of the Thurso Flag type, but rather more distinct from one another in colour than usual, and with the sandstones form a more easily recognisable sequence which, with intervals in which flagstones predominate, is repeated again and again for many hundreds of feet. This type of beds is called the Mey Beds from this district. The fish-bearing bands are very numerous and more easily picked out than where flagstones predominate. They contain *Thursius pholidotus* and *Coccosteus minor*. The sandstone bands are pale in colour and, like those of the Ackergill Beds, are often partly or wholly replaced by beds full of subangular and more or less rounded lumps of sandstone in a mudstone matrix. These peculiar "nodule beds" are, however, better developed and more numerous in this section. Ripple-marked beds and sun-cracks are beautifully exposed, and are easily examined as the coast is very accessible.

Near St. John's Point the sandstones intercalated in the flags become red and friable like those of the John o' Groat's Sandstones. At Scotland's Haven these beds are suddenly truncated by a north and south fault which throws down the John o' Groat's sandstones of Gills Bay.

JOHN O' GROAT'S SANDSTONE OF GILLS BAY.

The line of the Scotland's Haven fault is buried beneath the drift forming the back wall of the Haven. About half a mile farther south its position is indicated by a spring in the peat which has deposited a considerable quantity of calcareous tufa. It is also well marked in the Burn of Gills and the East Burn of Gills which enter Gills Bay in close association.

The sandstones which form the reefs below the boulder-clay cliffs fringing Gills Bay are limited on their west side by the Scotland's Haven fault. They surround the bay from Scotland's Haven to a short distance east of the Ness of Quoys, where they terminate in another fault which runs in a south-westerly direction to meet the Scotland's Haven fault about a quarter of a mile south of the jetty in Gills Bay. The Ness of Quoys fault throws down to north, so the sandstones of Gills Bay are isolated by faulting from the rest of

* *Quart. Journ. Geol. Soc.*, vol. xv., 1859, p. 402.

the rocks in the coast section. They are, moreover, arranged in a syncline dipping to the east and north-east away from the Scotland's Haven fault, and to the north and north-west away from that of the Ness of Quoyoys.

Good sections of the sandstones in the Gills Burn and the East Burn of Gills are continuous with those in the coast section. The sandstones are friable and mostly brick-red in colour but also have pinkish and yellowish bands in the middle of the bay. They exhibit marked current-bedding and frequently have numerous little angular pieces of green shale arranged along the curved planes of bedding. These pieces of shale are perhaps derived from flagstones older in the series. Thin, gritty bands may sometimes be noticed. Near the middle of the basin there are two bands of pale-weathering flagstone containing fragments of fish. The bands are similar in character to the fish bands of the Mey Beds, and are separated by sandstones of a paler colour than those elsewhere in the bay. There are altogether about 650 ft. of beds exposed between the faults in Gills Bay.

THURSO FLAGS AND MEY BEDS OF HUNA.

East of the Ness of Quoyoys fault flagstones form shore reefs bare at low water to a quarter of a mile beyond the Ness of Huna. The beds dip continuously to the east and north-east at angles of 5° to 20° , but from the sudden changes in the direction of dip at points on either side of the Lifeboat Station and at the Ness of Huna, they are probably traversed by at least three faults. Two near the Lifeboat Station seem to extend inland in a south-easterly direction to outline the abrupt elongated feature of Mool Hill.

The rocks in this coast section are locally similar to the Mey Beds. They show the same alternations of pale-weathering calcareous flags with fine, greenish-white sun-cracked beds, sandstones, and "nodule beds."

The fish bands contain *Coccosteus minor*. The beds west of the faults at the Lifeboat Station contain red and yellow bands of sandstone, and are probably higher in the series than those farther east. The faults at the Lifeboat Station therefore, in all probability, throw down to the west. East of the Ness of Huna the flagstones are truncated by a large north and south fault which can be traced a long way inland. To the east of this fault, false-bedded friable red and yellow sandstones, similar to those in Gills Bay, are again encountered. They dip persistently at 15° to the east-north-east as far as the Ness of Duncansby, and form shore reefs backed by blown sand. At the Ness of Duncansby, where they are pierced by the volcanic necks, they dip round gradually to the north-east, north, and north-west at angles of 10° to 15° , the beds forming the promontory being arranged as a shallow syncline. To the east of the Ness in the Bay of Sannick the beds continue dipping to the north-west at steeper and steeper angles until they are faulted against the flagstones forming Duncansby Head.

There are three thin bands of pale-weathering flagstones intercalated in the sandstones of this coast section. Two occur near one another in the rocks forming the Ness of Duncansby, and the third



WIFE GOE, 2½ miles south of Duncansby Head.

nearer the John o' Groat's Hotel. The latter has yielded the fossil fish *Microbrachius Dicki*, *Tristichopterus alatus*, and *Dipterus macropterus*. These fish have been found in Caithness only at this locality. The thickness of the beds exposed in upward succession from the fault at Huna must be about 1700 ft. The lower beds to the west of the John o' Groat's Hotel are yellowish and reddish sandstones. The higher beds are mostly brick-red in colour, but the beds lying between the two flagstone bands of the Ness of Duncansby are paler.

THURSO FLAGS OF DUNCANSBY HEAD.

The flagstones forming Duncansby Head are bounded on the west by the fault in the Bay of Sannick. This fault, the Duncansby fault, defines the north-east side of the hollow which extends across the base of the promontory from sea to sea. The flagstones are almost horizontal but dip towards the fault in its vicinity. They are probably high up in the Thurso Flagstone Group since they have bands of red sandstone intercalated near the top of the cliff.

JOHN O' GROAT'S SANDSTONE OF DUNCANSBY.

South of the Duncansby fault the yellow and red sandstones of the John o' Groat's group form magnificent cliffs for a distance of two miles. For the first half mile the beds dip to the north-west in continuation of the eastern limb of the syncline at the Ness of Duncansby, but a short distance south of the famous Stacks of Duncansby (Plate I.) a fault enters the cliff along the strike of the beds and extends inland to the north of the Biel of Duncansby. South of this fault, which throws down to north, the dip is in the same direction but at lower angles, and beyond the Hill of Crogodale, where the cliff reaches an altitude of 250 ft., the beds become horizontal as far as another fault near Fast Goe.

THURSO FLAGS OF SKIRSA AND THE BIEL OF DUNCANSBY.

This fault enters the cliff obliquely in a north-westerly direction and extends to the east of the Biel of Duncansby to meet the fault described above. It must have a big downthrow to the north since the whole height of the cliff to south consists of flagstones. They are, however, stained red as far as Fast Goe, and without examination might be mistaken for the red sandstones. Farther south they form splendid cliffs as far as Skirsa Head. They also extend inland to the Biel of Duncansby.

Near Fast Goe and the Biel the beds are dipping to the north, but farther south near Wife Goe they are horizontal (Plate IV.), and at Salt Skerry begin to dip to the south. From Salt Skerry to Skirsa Head the dip gradually changes from south to south-west and west-south-west, and increases from 3° to 20°.

The flagstones of Skirsa Head are like those at Duncansby Head, and have intercalated bands of red sandstone. Fossil fish have been obtained at Skirsa Head and the Biel of Duncansby, and include *Thursius pholidotus* and *Glyptolepis paucidens*, but *Coccosteus minor* has not been detected.

THE JOHN O' GROAT'S SANDSTONES OF FRESWICK BAY.

In the low cliffs forming the north side of Freswick Bay west of Skirsa Head, the flagstones underlie the yellow and red sandstones of the John o' Groat's group. There is a slight difference in the dip of the sandstones and flagstones which suggests an unconformity, but inland in the Skirsa district and at Black Hill the sandstones have the same dip as the flagstones in the coast section.

It is, however, probable that the John o' Groat's Sandstones are locally unconformable to the flagstones. From the sudden, widespread and lasting change in the character of the deposits on the incoming of the John o' Groat's beds, we would infer that great geographical changes occurred. These may have led in places to erosion of deposits already formed. The yellow and red sandstones north of Freswick Bay dip to the west-north-west at angles of 15° to 20° . Scattered exposures of these rocks are found in the Skirsa district, at Black Hill, in the Gill Burn near the Bridge of Freswick, at Everly, Warth Hill, and along the main road to Cannisbay for two miles from Freswick. North of Freswick the dip gradually changes to the north-west and north. Over most of the area round Warth Hill the rocks are hidden beneath the peat, but sandstones with the same northerly dip are again at the surface about three-quarters of a mile north of the hill. There is little doubt, therefore, that the sandstones extend continuously from Freswick Bay to the north coast at John o' Groat's and the east coast south of Duncansby Head. They are bounded by the east and west fault in Freswick Bay, the north and south Huna fault, the Duncansby fault, and the faults at the Biel of Duncansby, and pass down into the Thurso Flagstones along a north and south line between Skirsa Head and the Biel.

The sandstones of Gills Bay are like those of John o' Groat's and show similar faulted relations to the flagstones. The two flagstone bands at Gills Bay and the Ness of Duncansby belong in all probability to the same horizon, but have not as yet yielded determinable fish remains. The John o' Groat's fish band would lie beneath the sandstones of Gills Bay, so that the faults of Scotland's Haven and the Ness of Quoys appear to have a large throw.

The total thickness of the John o' Groat's group is difficult to estimate. It must be considerably greater than the 1700 ft. found in the John o' Groat's section. If the junction of the sandstones with the flagstones is everywhere conformable, there may be between 3000 and 4000 ft. exposed between Freswick and the north coast. It is, however, more probable that the junction is locally unconformable.

In the coast sections between Freswick and Dunnet we may give conservative estimates of the thickness of the strata as follows:—

John o' Groat's Sandstone Group	..	..	..	2000 ft.
Thurso Flags and Mey Beds	..	..	..	5000 „

In the coast sections between Wick and Freswick:—

	Thurso Flags and Ackergill Beds	..	..	?
Passage Beds.	{ Noss Beds	..	..	250 +
	{ Castle Sinclair Flags	..	..	400 +
	{ Field Beds	..	..	700
	{ Papigoe Beds	..	..	1000

There is, unfortunately, no section in Caithness giving a direct succession from the top of the Wick Flagstone Group to the John o' Groat's Sandstones.

The strata of the Passage Beds are probably considerably thicker than the 2350 ft. exposed.

There is in all probability a repetition of the flags of the Nybster coast section in the Ham Anticline, but the Thurso Flagstone Group is probably of greater thickness than the 5000 ft. exposed on the north coast.

STRUCTURE OF THE NORTH-EAST OF CAITHNESS.

The greater part of the area inland east of the Brough fault is covered by drift or peat, but the rocks are often exposed in quarries and drains.

The rocks are almost certainly as much dislocated by faults as those in the coast sections, and the structure must be very complicated. Well-marked rucks are known at Coghill, Todholes, Smerral, Lochside, Barrock Mill, Aucorn, Hollandmey, and elsewhere, but the extent of dislocation of the rocks, if any, is unknown.

Without attempting any detailed description of this area, we may point out that the rocks in the neighbourhood of the Brough fault dip to the north-east in the Dunnet area, to the east about Bowertower, and to the south-east in the North Watten district. The south-easterly dip of the North Watten district is continued in the Killimster and Reiss areas as far as the centre of the Ackergill Syncline. The easterly dip at Bowertower continues to the coast at Keiss and Auckingill, while the north-easterly dip of the Dunnet area is found over the remaining country to the north in Mey, Brabstermire, Warse, Seater, and Duncansby.

Disregarding perforce the unknown faults, the lowest beds should occur in the Bowertower district, while higher beds would be found as we proceed south-east, east, and north-east.

The beds in the North Watten and Bowertower districts are for the most part sandstone and black thin-weathering flags in which only a few scattered fish scales have been noted. The rocks resemble the Helman Head Beds, with which they may be placed provisionally.

Rocks resembling the Wick Flags are found in Watten, Lyth, and Reaster districts. A hard dark sandstone, resembling the massive band in the Papigoe coast section, occurs in the stream section below Barrock Mill. The beds in the Killimster district have black bituminous shales like those of Ackergill. The rocks farther to the north and east belong to the Thurso Flagstone Group. *Thursius pholidotus* has been obtained from quarries at Systar. Beds of the Noss Head type are exposed near Brabstermire.

CHAPTER VII.

THE WEST OF CAITHNESS.

BEN ALISKY, STRATHMORE, AND SCOTSCALDER AREA.

THE district now to be described comprises the high ground around Ben Alisky (Sheet 109), Strathmore down to Dirlot Castle (Sheets 109, 110, 116), and the tract of moorland stretching from Cnocglas Water south from Loch Shurrery eastwards to Scotscalder and Westerdale (Sheets 115, 116). The following subdivisions of the system in descending order may be recognised in this part of Caithness :—

3. Grey, sandy, calcareous flagstones and shales, with occasional bands of dark blue, impure limestone, or highly calcareous flagstones, and grey and yellow sandstones (Dorrery, Scotscalder, and Westerdale).
2. Red false-bedded sandstones, flagstones, and shales with wavy false-bedding, containing bands of brecciated conglomerate and grit (Ben Alisky, Strathmore, and Cnocglas Water).
1. Coarse basement conglomerate (Beinn Glas-choire and Cnoc na Sao-bhaidhe).

The greater part of this district is covered with a thick mantle of peat, and the boundary lines for the above subdivisions are based on rock exposures in streams and on the moorland, usually at great distances from each other. The two lower subdivisions may be regarded as representing the succession of red strata, which so far have yielded no fish remains. In this respect they resemble the sequence of red strata ranging from the basal conglomerates and breccias up to the top of the Berriedale Sandstones in the south-eastern part of the county, which has already been described. Indeed, the boundary laid down on the maps as marking the upper limit of these red beds in the central portion of Caithness, is a prolongation of the line drawn at the top of the Berriedale Sandstones in the Berriedale and Dunbeath districts.

The coarse conglomerate that marks the base of the system south of Strathmore and east of Glutt Lodge is best seen on the hills near Ben Alisky where the rock protrudes through a thin covering of turf. It is a coarse, tumultuous, consolidated shingle, with hardly any trace of stratification, the larger blocks lying in different directions and at different angles. Sometimes it is merely an assemblage of boulders with little or no matrix; sometimes it merges into a rock like a fine breccia with scattered pebbles, the materials forming the pebbles having been derived from the disintegration of gneiss or granite. The component blocks sometimes measure from 2 to 3 ft. across, and consist of granite, granulitic gneiss, coarse biotite-gneiss, quartzschist, and other crystalline rocks, which are all of local origin. The conglomerate varies in character according to the nature of the under-

lying platform. Thus on Beinn Glas-choire, where the floor consists of crystalline schists with granite veins, the schist blocks are abundant, while farther south on Cnoc na Saobhaidhe, where the conglomerate and breccia rest on granite, the matrix and included pebbles are mainly granitic. Owing to the absence of stratification in the conglomerate, it is difficult to give a reliable estimate of its thickness, but on the assumption that the mass is horizontal, it cannot be less than 200 ft. thick on Beinn Glas-choire. This basement subdivision has not been traced northwards to Strathmore and Cnocglas Water.

The conglomerate passes upwards into red false-bedded sandstones, flags, and shales, with bands of brecciated conglomerate and grit (No. 2 in foregoing table). These breccias and grits are composed mainly of granite detritus, and the pebbles in them likewise consist of granite. Perhaps the most persistent member of this subdivision is a red sandy flagstone or sandy shale with a peculiar wavy stratification. The passage upwards from the basement conglomerate into the sandstones and grits of the overlying subdivision is to be found on the higher part of Ben Alisky, where the latter dip to the east or east-south-east at about 14°. Between Ben Alisky and Cnoc Allt a' Chait, the two lower subdivisions are intersected by a north-west and south-east fault with a marked downthrow to the south-west. Farther north, in the district of Strathmore, the red grits and sandy flags are exposed in pits by the roadside near Strathmore Lodge, in the Thurso River, where it issues from Loch More, and near the source of the southmost tributary of Loch Ruard, about four miles south-east from Loch More. Still farther north we find a section in the Cnocglas Water (Sheet 115) about a mile and a half south from Loch Shurrery. Here the unconformable junction is not visible, but the red sandy flags with a gentle north-easterly dip are to be found at the roadside near the stream within a distance of 250 yds. from the gneiss with granite veins. No basal breccia is there to be seen, and if it does exist, it must be comparatively thin. Farther down, there are various exposures of red sandy flags, micaceous sandy shales, and occasional bands of false-bedded grit, all dipping generally in an east-north-east direction with several minor undulations. The minimum thickness of this subdivision across the belt about a mile and a half south from the Cnocglas Water must be about 1000 ft.

Next in order comes a group of grey, sandy, and dark blue calcareous flags and shales interstratified with grey and yellow sandstones (No. 3 in foregoing table). It includes occasional bands of dark blue impure limestone, which, in certain localities, have yielded fish remains. No satisfactory continuous section of the members of this subdivision is to be found within the area now under description, but there can be no doubt that they represent a considerable portion of the Wick Flagstone series. Lithologically they resemble the dark weathering flags of the Helman Head Beds and Wick Flags while palæontologically there is a resemblance between them from the occurrence of the same species of fossil fish remains in the beds of the respective areas, viz., *Thursius macrolepidotus*.

The lowest members of this subdivision in the area under description are to be found in a burn one-third of a mile south from Lochan Dubh a' Chracairnie (in Sheet 115), and about three miles south-south-east from Loch Shurrery. They consist of grey, sandy flags, dark

blue calcareous flags, and grey sandstones, which appear close to the line that marks the top of the underlying red groups. No organic remains have been found in these beds. About a mile to the north of this locality, however, fossils have been obtained in a rock cutting in the Highland Railway, half a mile east-south-east from Druim a' Chracairnie (Sheet 115), and about two and a half miles from Scots-caldar Station. Here, beneath a covering of peat and boulder-clay, we find dark blue flags and a thin band of dark blue limestone, overlain by blue calcareous flags and grey sandstone, dipping towards the north-east at angles varying from 5° to 7° . After a careful search Mr. Tait collected from this exposure thirty-three specimens of fish remains, which were determined by Dr. Traquair. Three of the specimens were named *Thursius macrolepidotus* (Sedgw. and Murch.), and thirty of them *Thursius sp.* These fossiliferous beds must lie about 500 ft. above the top of the red strata that have yielded no fish remains (Groups 1 and 2 of foregoing table).

Farther east there are numerous exposures of the members of this subdivision higher up in the sequence, in the tract stretching south-south-east from Scots-caldar Station by Appat Hill to Achlibster and Westerdale. The dominant type here comprises dark blue calcareous flags with abundant worm casts, grey sandy flags with ripple marks, and shaly bands. Occasional intercalations of grey sandstone occur. A bed of dark blue limestone, 1 ft. 6 ins. thick, was recorded in a quarry one-third of a mile south-west from Achlibster farmhouse, where it was underlain by massive dark blue and grey flags, and covered by thin micaceous flags. Throughout this tract the strata dip east-south-east, east, and east-north-east at angles varying from 3° to 10° .

In the course of the geological survey of the district a suite of fish remains was collected from a quarry about half a mile west from Westerdale Bridge, which, on being submitted to Dr. Traquair, were referred by him to one species, viz., *Thursius macrolepidotus*.* Plant remains have also been detected in the beds near Westerdale.

The succession of strata between the Westerdale flagstones and those in the Achanarras quarry with the distinctive fish fauna described by Dr. Traquair, is dealt with by Mr. Carruthers in the next section, so that an estimate may now be given of the thickness of the sediments ranging from the base of the red strata near Cnocglas Water (Sheet 115) to the Achanarras flagstones (Sheet 116) in the central part of the county. Such an estimate can only be an approximate one owing to the concealment of the evidence by peat and glacial deposits over wide areas. But on the assumption that no powerful fault traverses this district, and taking an average angle of 7° , we find that the total thickness must be about 5000 ft.

About two miles south from Westerdale the crystalline schists appear within the Old Red Sandstone area in the gorge of the Thurso River at Dirlot Castle. In 1858,† Sir Roderick Murchison gave an account of this section, having been led to visit it in company with Mr. C. W. Peach, at the suggestion of Mr. Robert Dick. He maintained that the older conglomerate and sandstone here protrudes

* Dr. Traquair informs me that *Thursius macrolepidotus* is the only species observed by him from the localities at Westerdale. J. H.

† *Quart. Jour. Geol. Soc.*, vol. xv., 1859, pp. 396, 397.

through the broken undulations of the Caithness flagstones as at Sarclet, south of Wick. He pointed out that the "crystalline rock, dipping sharply to the east-south-east, is surmounted by a coarse conglomerate almost a breccia, which inclines to the north-east at about 10° , and soon graduates up into purplish and grey siliceous and micaceous thin-bedded sandstones, covered by the true dark-grey (in parts almost bluish) flagstones, which, after curvatures (doubtless accompanied by breaks which are hidden by moss), become highly fossiliferous in the adjacent hills of Banniskirk." In the gorge, the crystalline schists are exposed on two separate arches, the lower one measuring 200 yds. in length, and the upper one about 600 yds. They consist of grey granulitic biotite-gneiss, either vertical or inclined at high angles to the east or north-east, and traversed by numerous granite veins. The schists of these exposures are surmounted by a thin conglomerate or breccia made up of the underlying rocks, which is best displayed in the arch farther down stream than Dirlot Castle. It is followed by grey sandy flags, weathering yellow, micaceous flagstones and shales with occasional dark bands, thus differing in character from the false-bedded red sandstones and wavy red shales of Ben Alisky and Loch Shurrery. It is therefore probable that these sediments merely represent a local base in the Dorrery and Westerdale series.

J. H.

ACHANARRAS AND HALKIRK DISTRICT.

On the two sides of the line of the Brough fault, west of Watten, a striking difference is noticed in the colour of the flagstones. The drab weathering of the group, seen on the east of the fault, is replaced by delicate shades of pale ochre and blue, blended in innumerable half-tones.

These are the weathering colours so characteristic of the Thurso Group; they are a striking feature of the country north of a line drawn, say, from Spital through Halkirk to Reay, in which they are seen in numberless quarries and flag fences.

Taking into consideration the whole area west of the fault line, the general inclination of the strata gradually swings round from an easterly direction near Spital and Westerdale to north-west between Reay and Forss. This disposition is brought out on tracing the outcrops of the Spital flagstone horizon, and of the underlying limestone bands.

South of Halkirk all the strata belong to the dark-weathering Wick Flagstone Group. These beds are well seen at many localities; there are typical sections in the quarries round Westerdale, and in the river Thurso, south of Gerston (Halkirk). "Limestone" bands are not very common, but then much of the ground is obscured with drift deposits; one of the best exposures is in the bend in the river $\frac{1}{4}$ mile east of Halkirk Bridge, and this bed will be again referred to.

West of Spital, at the junction of the two great flagstone groups, lies the famous quarry of Achanarras. The stratigraphy of this part of the area is of such interest that it will be considered in some detail.

In the Achanarras quarry itself, the section is now somewhat obscured, as very little working has taken place for several years.

A very careful description has been given by Dr. Traquair,* to whose account the reader is referred for full details. The following notes were taken recently under less favourable circumstances.

The "limestone" flag is from 8 to 10 ft. in thickness, and the lower part is extremely hard when first quarried, splitting along the bedding planes with a rough hackly fracture. The flags, when fresh, are from 1 to 4 inches in thickness, but shade off above (and apparently below also) into beds that split much more readily, so much so that after some exposure to the weather they are little better than papery slates or shales.

Palæospondylus seems to occur throughout the limestone bed, but *Pterichthys* is usually found in the hard rough-splitting bed. The upper part of the "limestone" splits into smooth micaceous layers, in which the commoner fishes, especially the Acanthodians, are well preserved.

The fish remains are seen much more distinctly after the flag has weathered for a few months, when they assume a light blue colour, owing to the formation of phosphate of iron.

Small exposures of the overlying strata are seen close to the farm steading of Achanarras, and also on the crest of the hill; slightly higher beds can be seen in the streamlet east of the farm. These strata all show the weathering colours characteristic of the Thurso Group; they pass under the flagstones of the Spital quarries, which are much harder, and weather in somewhat darker tints.

All these strata are very different from those that underlie the Achanarras "limestone." Numerous small quarries in these lower beds can be seen along the roadside between Halkirk and Westerdale, in the railway cutting at Scotsalder Station, etc.; in every case these flagstones are of the Wick Flag type—rough, hard, and weathering dark grey or blue. Indeed, as remarked above, the strata in general, between Achanarras and the western boundary of the Old Red, belong to the Wick Flagstone Group.

The strata around the Achanarras position are again seen near Halkirk, where supplementary details can be obtained.

At the sharp bend in the river Thurso, $\frac{1}{4}$ mile east of Halkirk Bridge, there is an outcrop of "limestone" overlying dark flagstones of Wick Flag type. This "limestone" is 18 ins. thick, and is unusually pure; it weathers very pale grey or blue and exactly resembles that seen at Robbery Head, on the Latheron coast. The bottom layer of this "limestone" contains abundant, but poorly preserved, remains of Acanthodians, and of *Thursius*; the same bed is exposed in a small stream section $\frac{1}{2}$ mile south-east of Blackpark.

Succeeding the "limestone" there are about 100 ft. of hard slaty flags, well exposed in the river section above and below Halkirk Bridge. Fissile beds of the same character are also seen near Achanarras, and above the "limestone" at Robbery Head.

In the Halkirk section, just below the churchyard, a thin fish band can be seen in the upper part of these "slates." At Braal Castle the section is brought to a close, an unfortunate circumstance, since the evidence obtained on the Latheron coast and in the immediate

* "Achanarras Revisited," *Proc. Roy. Phys. Soc. Edin.*, vol. xii., 1894, p. 279.

neighbourhood, leads to the supposition that the Achanarras "limestone" must cross the river Thurso about 100 yds. below the Castle.

To the north-west of Halkirk, sections along the strike of these beds are few and far between. South of Buckies Hill, however, the Spital Flags reappear and continue on to the well-known Achscrabster Quarries. Here the flagstones have been worked extensively; they are practically identical with those at Spital itself—very hard, in beds 2 and 4 inches thick, and dark grey when freshly quarried, but weathering in dull variegated colours of the Thurso type.

The Achanarras "limestone" is not definitely known hereabouts. The bed may perhaps be found at an old quarry on the east side of the main road near Framside. At this spot fragments of a "limestone," which is lithologically like that at Achanarras and contains abundant plates of *Coccosteus*, can be picked up on the refuse heap; the section is now almost obscured by talus.

Fissile flagstones, or "slates," identical with those underlying the Achanarras bed, can be seen in quarries on the hillside $\frac{1}{2}$ mile south-south-west of Framside farm, and can be traced down to Lochside, by Loch Calder.

The westerly termination of the Achscrabster quarries is marked by an increase in the dip of the strata to 12° , and an alteration in direction from north-west to north-north-east. These changes are probably due to the proximity of the line of disturbance running along the eastern shore of Loch Calder; farther west the flagstones have not been recognised.

To the north and north-west of Achscrabster there appears to be a continued upward succession in the Thurso Group, the highest beds being reached in the coast section between Crosskirk and Reay. In this north-westerly portion of Caithness, four beds of flagstone have been extensively wrought, namely, at Janetstown, Hill of Forss, Scrabster, and Holborn Hill—the last mentioned being the highest. In all these cases the flagstones have dull "Thurso" weathering colours, but are much softer than the Spital and Achscrabster flag. In other cases the weathering colours are remarkably brilliant (Crofts of Achimore, Stemster Hill, Milton, etc.), but the flags are fissile and of poor quality.

Plates and scales of fishes are of very common occurrence, but except at certain parts of the coast section, to be presently described, whole fish are certainly rare. For such specimens the best inland locality at the present time is the small roadside quarry $1\frac{1}{2}$ mile west of Shebster, where there is a band of dark "limestone" flag, full of *Thursius macrolepidotus*, in indifferent preservation. This "limestone" and also the strata in immediate association, strongly resemble those in the Lower Group. Nevertheless the bed is regarded as a recurrence of the Lower type of sedimentation within the Thurso Group, for the overlying flags, seen in old quarries a few hundred yards north of the road, are of very marked Thurso type, as also are the underlying strata seen farther south.

R. G. C.

CASTLETOWN AND THURSO DISTRICTS.

The beds in the coast section between Thurso and Castletown dip

uniformly to the north-north-west at angles of 5° to 10° . The cliffs are low, with shore reefs, and the rocks are easily examined. They are much less disturbed than those in the sections east of the Brough fault. Small crushes and displacements along the joint planes are not uncommon, but except at Murkle there is no deflection from the gentle north-north-westerly dip. In Murkle Bay the rocks are much disturbed and a fault is almost certainly present. There is, however, no positive indication that the fault is a large one. Yellow friable sandstones on the south-east side of the bay resemble those of the John o' Groat's Beds. Similar sandstones are met with in Thurso Bay between Thurso and Scrabster. The flagstones in the vicinity of these sandstones at Murkle and in Thurso Bay have yielded *Thursius pholidotus* and *Cocosteus minor*. The character of the yellow sandstones suggests that at these localities the horizon of the beds is not far below the John o' Groat's Sandstone group, and that the beds at Murkle are repeated at Thurso by faulting. It is, however, more probable that they form two distinct horizons in the coast section, since yellow sandstones of a similar nature are found inland along the strike of the rocks for long distances at both localities. Such sandstone horizons may be compared with the Ackergill Beds and Mey Beds which also contain *Cocosteus minor*. The thickness of the beds in the coast section between Thurso and Castletown can at the most be 300 or 400 ft., so the sandstone horizons are probably not far apart. Other sections of the rocks along the coast line resemble the Mey Beds in every detail. They show the same regular repetition of pale blue or buff-weathering calcareous flags with fish remains, greenish-white sandstones with sun-cracks, and pale, fine-grained sandstones. The curious "nodule beds," so characteristic of the Mey Beds, are even better developed in the section west of Thurso than at Mey (Plate VI.). They form wide areas of the rocky platform exposed at low tide about half a mile north-east of Thurso Castle, and other good sections are found to the east and west of Clardon Haven. Examination of these sections proves that there is a number of these conglomerate-like beds and that they recur in definite sequence with the other beds in the coastline. They are invariably in association with the ripple-marked sandstones and sun-cracked beds which alternate with the smooth-bedded calcareous flags with fish remains. The materials of which they are formed are the same as those of the beds with which they are associated, and there is no reason to suppose that the fragments have been carried great distances. The sandstone fragments are angular or more or less rounded, but never pebble-like, and the matrix is a sandy mudstone. The rounded fragments are small, but larger areas of flaggy sandstone appear crumpled and distorted but not far displaced.

The smooth calcareous flags contain *Glyptolepis paucidens* and *Dipterus Valenciennesii*. *Thursius pholidotus*, *Cocosteus minor*, and *Mesacanthus* have been obtained from Murkle Bay. *Estheria membranacea* occurs in the beds east of Thurso.

Inland, the lowest beds of the shore section must be continuous with those in the quarries at Castlehill, Stonegun, and Weydale. These Thurso Flags resemble the rocks at Ham and Nybster.

South of these quarries, in the district of Hilliclay, the rocks are almost horizontal, but farther east, from the Hill of Olig southwards,



1. BELT OF CRUSHING AND OVERFOLDING IN FLAGSTONES, Holborn Head.



2. NOSS HEAD, $2\frac{1}{2}$ miles north of Wick.

the beds dip at gentle angles to the east. The same beds must cover a very wide tract of country, as the dips are gentle. The beds from Loch Scarmclate, through the Hill of Olrig to Weydale, are probably on the same horizon. The rocks are pale-weathering like those in the quarries at Weydale and Stonegun. Fish remains are abundant, but only *Osteolepis microlepidotus* and *Coccosteus decipiens* have been definitely recorded. *Estheria membranacea* is common in quarries from Sordale to Bishop's Hill and the Hill of Olrig.

C. B. C.

COAST SECTION—THURSO TO REAY.

The shore section immediately west of Thurso is largely occupied by bands of rather soft false-bedded sandstone, weathering pink and yellow. These strata can be traced some miles inland towards the Forss Water.

Farther north, in the Scrabster quarries, soft leaden-grey flags are seen, succeeded by the thin-bedded flagstones of Holborn Head (Plate V., 1). The Holborn Head beds resemble in many ways those of Noss Head, north of Wick, more especially in their thin-bedded character and in the presence of thin lenticles of cream-weathering "calmstone." The Holborn Head beds, although rather dark, weather in paler colours—light grey, cream, or blue—and isolated fragments of fish are not uncommon.

For a mile or more west of the head, the flags can only be examined on the verge of the cliffs, which are perpendicular, or even overhanging. The weathering colours of the Thurso Group are well seen, and become pronounced farther west, between Ness of Litter and Port of Brims. At this part of the coast, the cliff breaks down considerably, and the strata can be clearly examined; the fine casts of sun-cracks and the abundance of fish scales on certain beds of the rough flags are very noteworthy.

At Port of Brims the gently ascending succession is broken by a line of disturbance running in a north-north-east direction. The amount of actual displacement so caused seems to be slight; the evidence on this point will be noted subsequently.

Round Brims Ness the flags weather in pale leaden colours. On the shore, a hundred yards or so west of the chapel ruins, a band of hard "limestone" is met with, having a rough hackly fracture, and very pale blue or grey weathering. Lithologically, the "limestone" exactly resembles those found on the east coast, towards the top of the Lower Flagstone Group (Papigoe and Robbery Head "limestones"). Well-preserved remains of *Thursius macrolepidotus* are abundant in this bed.

About two hundred yards west of the chapel ruins, a small reversed fault is seen, on the west side of which there is a well-marked anticlinal fold; this fold can be traced inland for a quarter of a mile, when it is again visible in a small flagstone quarry.

Another "limestone" band is found at this point of the coast, and there are at least three other bands, all of the Papigoe type, farther west, on each side of Crosskirk Bay. The flags associated with these "limestones" weather a pale yellowish grey, and they contain abundant nodules of iron pyrites.

West of Crosskirk Bay the succession is still a gently ascending one for some distance. The Thurso weathering colour is marked, and pyritous nodules are common. Fish remains, often of the *Coccosteus* type, are abundant in certain layers.

On the west side of the inlet known as Gie-uig Goe there is a band of papery flag, but with this exception the general character of the strata does not differ from that seen east of Port of Brims.

Near Reay the strata strike along the coast line, and the Crosskirk "limestones" reappear on each side of Sandside Bay. On the east side of the bay, just north of the harbour, some of the "limestone," exposed between tidemarks, has been quarried for road metal, and *Thursius macrolepidotus* can be collected in some abundance.

This Thurso-Reay coast section has been described above as a gradually ascending succession within the Thurso Group; that interpretation, however, is by no means free from difficulty.

In the first place, the red and yellow sandstones seen on the south shore of Thurso Bay certainly resemble those of the John o' Groat's Beds, although they must lie not more than 2000 ft. above the Ach-scrabster flags, near the base of the group (that is if no faulting exists). It should be remembered, however, that in the Mey Flag division of the Thurso Group, bands of sandstone of somewhat similar type occur, and it seems more reasonable to correlate the latter with the Thurso Bay sandstones; otherwise, extensive faulting, of which there is no direct evidence, must be supposed to exist between Ach-scrabster and Thurso Bay.

The partial resemblance of the Holborn Head flags to the Noss Head division of the eastern sequence has already been noticed; a direct correlation with the Noss Beds would necessitate, as in the previous case, the presence of a large fault of which no direct evidence exists. The resemblance to the Noss Beds is, however, by no means close enough to warrant such a conclusion, and the associated strata seen west and south of Holborn Head are certainly of Thurso type.

The difficulty of interpretation is more serious with regard to the Crosskirk "limestones." In this case the whole coastal strip, from Brims Ness to Reay, is involved. The thickness of strata is not great (about 330 ft.), but the "limestone" bands, three or four in number, are all of a type unknown elsewhere within the Thurso Group; on the other hand, beds lithologically similar are known in the upper part of the lower flagstones (Papigoe and Robbery Head "limestones").

If the Crosskirk beds be correlated with the Papigoe "limestones," they must be faulted off from the flags of undoubted Thurso type, which are found to the south and east; such a fault may exist at the crush line seen at Port of Brims.

There are, however, several points against such a reading. The Papigoe "limestones" are directly underlain by the Wick Flagstones, hard, rough, and dark weathering. The Crosskirk "limestones," on the other hand, are underlain to the south by several thousand feet of typical Thurso Flags, unless some large, hidden fault exists. These latter beds are seen in numerous quarries inland (Achreamie, Stemster Hill, etc. etc.).

There is the further point that the strata in immediate association with the Crosskirk "limestones" are in many ways of Thurso type.

The flags are not only soft and pale-weathering, but, like many other Thurso beds, they contain abundant nodules of iron pyrites, which are unknown in the flagstones associated with the Papigoe and Robbery Head "limestones." Lastly, *Cocosteus*, which is so common and characteristic a fossil in the latter bed, has not been found in the Crosskirk "limestones."

These considerations favour the supposition that the Crosskirk beds lie near the top of the Thurso Group. According to protraction, they should lie some 5000 ft. above the base of the group.

It should be added that the non-occurrence of such strata in the north-east of Caithness may be due to the probable unconformity between the John o' Groat's Sandstone and the Thurso Group, through which the equivalents of the Crosskirk beds may be hidden, or even eroded, in this part of the county.

R. G. C.

AREA BETWEEN CNOGLAS WATER AND SANDSIDE BAY (SHEET 115).

Owing to the very irregular surface upon which the sediments were laid down, there is an overlap of at least 4000 ft. of the Middle Old Red Sandstone strata upon the crystalline schists and granite between Cnocglas Water and Sandside Bay—a distance of about 12 miles. Indeed, it will be shown that all along the western margin of the Caithness basin within the above limits, the Old Red Sandstone was deposited on a land surface carved into parallel north and south ridges. Further, it will be shown that all the outliers west of the marginal line occupy old north and south valleys which drained northwards into that part of the Middle Old Red Sandstone basin now represented by the Orkneys.

The ground lying between the Cnocglas Water and the Achsteenclate Burn, which flows into the head of Loch Shurrery from the west, is mostly covered with peat or strewn with moraines, but red sandstones and red flags with wavy bedding are exposed here and there on knolls round Braigh Féith Hemigal about one mile north from Loch Caluim.

In the Achsteenclate Burn the red, wavy, bedded flags and red sandstones are visible at intervals for a distance of about a mile above Loch Shurrery, the dip being easterly at angles of from 15° to 30° . Occasional exposures of red sandstone, arkose, and the local basement breccia with the same easterly dip occur along the new driving road to Loch Seye for nearly a mile farther to the west. East of the mouth of the burn the red flags are to be found on the south shore of Loch Shurrery, and also on its eastern side, which they occupy for about a mile along the strike, the dip being east or north of east at angles from 25° to 60° , and in places nearly vertical. Eastwards the red shales are surmounted by a band of conglomerate with granite pebbles, indicating that the old granite floor was exposed somewhere to the west during its deposition. This conglomerate, which may be regarded as the highest member of the red subdivisions in the lower part of the system, passes beneath the dark flags with intercalations of grey and yellow sandstone of the Dorrery Hills. The latter may, in all probability, represent the Helman Head Beds of the east coast.

North from Loch Shurrery this conglomerate can be followed along the slope for more than a mile, dipping beneath the Ben Dorrery

Beds, the underlying red sandstones, flags, and shales of Berriedale type being visible along the course of the Forss Water, all inclined to the east. Beyond this point, the dip suddenly changes to the north, and the boundary between the red beds and the overlying grey strata of the Dorrery Hills swings round to the westwards.

Attention will now be directed to the section in Allt Forsiescye, which drains Loch Scye and joins the Forss Water about a mile and a half north from Loch Shurrery. At a point about a mile and a quarter north-east from Loch Scye and near the ruins of Ach Forsiescye, a coarse breccia, composed chiefly of granite debris, is to be found in the stream with a north-easterly dip. Its junction with the old rocks is not visible, but there can be no doubt that it is the basal member of the series, as the granite appears on the hill slope not far from the breccia. Farther down the stream forks, and the overlying red flags, inclined to the north-east at 15° to 20° , occur in both branches. Below this point, for about a mile, the strata are largely concealed by alluvial and glacial deposits, but red flags and ripple-marked red sandstones are exposed at long intervals. They are to be seen in the bed of the stream where it bends to the east about a mile south from Brubster Hill, with a north-easterly dip. Here there is a gap in the section for a distance of about 200 yds., beyond which the grey and yellow sandstones of the Dorrery group are to be found. There is no evidence in this stream of the existence of the conglomerate that intervenes between the red beds and the Dorrery group to the south-east. If it does occur it must be concealed under the alluvium and glacial deposits. Along the section just described, the red strata must reach a thickness of from 800 to 1000 ft.

To the west and north of this latter section, the red flags, sandstones, and local basement breccia are occasionally exposed on the hill slopes and in the rills that drain into Loch Thormaid. Immediately to the west of that loch, the rocks of the old floor protrude in a knoll,—Cnoc na Ruighean Dubh,—where they consist of coarse granulitic schists, traversed in all directions by veins of granite and pegmatite. The red mudstones and flagstones form the eastern shore of Loch Thormaid, the dip being to the south-west. They also occur at the north-east corner of Loch Saorach, while the grey sandstones and flags of the Dorrery group form the eastern shore of the loch, the strata in both cases being inclined to the east. In this part of the area the red beds must have dwindled to less than 500 ft. in thickness.

The rapid attenuation of the red beds is further demonstrated by a section exposed in a deep dry valley draining into the Achvarasdal Burn, where gneiss with granite veins is overlain by an arkose, which has apparently been laid down upon a steep slope of schists. The arkose is immediately succeeded by white and grey sandstones and flags of Dorrery type. If the red strata west from Loch Shurrery occur here, they must be represented by a small thickness of arkose.

No less remarkable evidence is to be found about half a mile to the north of this latter section, on Blàr Cnoc na Gaoith (Knoll of the wind). This knoll, composed of siliceous schists invaded by granite, projects through dark bituminous flagstones with fish remains. A local basement breccia in places intervenes between the flags and the

schists. Here there can be no doubt that fish-bearing flagstones of the Dorrery group abut against the old floor.

Blàr Cnoc na Gaoith is evidently the northern extension of a ridge of gneiss and granite, trending north and south, which extends still farther north, although now buried underneath the flagstones of Shebster. Evidence will now be adduced to show that to the west of this ridge a valley existed at the time of the deposition of the red beds, the trend of the valley being approximately north and south like that of the ridge. This ancient hollow, still partly floored with the red beds and the overlying strata of the Dorrery group, is now occupied by the upper reaches of the Achvarasdal Burn. This stream rises in Beinn nam Bàd Mòr (950 ft.), a hill composed of granite capped with coarse conglomerate, having a matrix of arkose or granite debris, in which lie boulders of granite, some of which exceed a foot in diameter. As the granite and overlying conglomerate are all much decomposed, it is sometimes difficult to determine the boundary between them. The disposition of the arkose on the north and west sides of the hill shows that it was laid down on a land surface sloping westwards; for in spite of a dip inwards towards the centre of the hill, the line between the arkose and the granite crosses the contour levels from above 900 ft. to 700 ft. on the north-west declivity. For some distance to the north of the hill, the head waters of the Achvarasdal Burn flow through peat and glacial deposits, but farther down the main stream cuts down into the underlying decomposing granite. At a point about a mile and a half from its source, it traverses the conglomerate and arkose which there form the local base of the red beds fringing the Caithness basin. Tongues of the breccia extend along the hill slopes on each side for nearly half a mile southwards, in such a way as to indicate that in the space between Blàr Cnoc na Gaoith and this exposure the stream has cut beneath the floor of the ancient valley.

For nearly a mile northwards from these exposures of basal conglomerates and arkose, as far as the junction of the second tributary from the west, the main stream displays a succession of red sandstones, grits, and conglomerates dipping steadily northwards at angles from 12° to 30° . After an interval of about half a mile, where the solid rocks are concealed by glacial deposits, grey flags like those of Dorrery and Scotscaidier appear in the section. These dip northwards at low angles, except at one point where they are thrown into an arch. Some of the bands of dark flagstone contain plant and fish remains.

Although the red beds and grey flagstones with an almost persistent northerly dip occur in the stream, yet the granite of the old floor is laid bare in the side burns and hill slopes a short distance off, thereby indicating that these sediments, or at least the red beds, must have been deposited in a narrow valley by a stream flowing northwards. Hence the northerly dip is due more to original deposition than to subsequent earth movement.

Following the Achvarasdal Burn farther north, we find that the solid rocks are not visible for about a mile. Here it bends towards the north-west and ultimately encounters the basement breccia on the west side of the old valley, crosses the breccia, and cuts into the granite east of Creag Leathan. From the disposition of the strata in this part of the section, it is clear that the basement breccia

must here represent beds high up in the Dorrery and Scotscaulder sequence.

Reference may here be made to the fact that limestone or calcareous sinter is of frequent occurrence near the junction of the sediments with the granite. At Aryleive, where an old limekiln is marked on the one-inch map 115, a bed of flaggy limestone of this character, from 10 to 15 ins. thick, was worked for lime. It encloses pebbles of granite and schist and is part of the basement breccia associated with grey flags and sandstones like those of the Dorrery group. A similar limestone has been wrought on the opposite side of the burn near the ruins of Achvarasdal. It laps round the eastern slopes of Creag Mhòr as indicated by the lines of swallow holes. The limestone or sinter at these localities is evidently a marginal phenomenon, and is probably due to calcareous springs emanating from the granite and cementing the debris that had accumulated on the old land surface during desiccation between sudden floods in Old Red Sandstone time.

Returning to the section in Achvarasdal Burn, we find that, to the north of Creag Mhòr, it flows in some places over the old floor of schist and granite, and in others over outliers of the local basement breccia, which must represent successively higher horizons of the flagstones. These strike nearly at right angles to the course of the stream with a persistent dip to the west-north-west. Near Achvarasdal Lodge, the burn crosses the mass of diorite at Reay, and a few hundred yards above the Bridge of Isauld it traverses the local basement beds of the flagstones, which are here also calcareous owing to the deposition of sinter. Below the bridge, yellow sandstones are seen lapping round the diorite bosses, the diorite being in places coated with concentric layers of sinter. The yellow sandstones are intercalated with grey flags and limestone bands containing remains of *Thursius macrolepidotus*.

At Reay the flagstones strike at the junction line of the local basement breccia with the old floor, and are inclined to the north-north-west. The strata abutting against the Reay diorite at the mouth of the Achvarasdal Burn must be over 2000 ft. higher in the series than those crossed by the stream two miles up the valley and to the east of Creag Leathan. This overlap was observed by Sir A. Geikie, and represented in a sketch map accompanying his paper on "The Old Red Sandstone of Western Europe,"* where the strike is shown by dotted lines. In the area north of Loch Calder the lines are fairly accurate, but to the south of that loch the actual strike is much more northerly than that indicated in the sketch map. B. N. P.

AREA BETWEEN SANDSIDE BURN AND BIGHOUSE BAY.†

This tract includes the western extension of the Old Red Sandstone of Caithness which crosses the county boundary into Sutherlandshire. Reference ought first to be made to an outlier of the basal beds that occurs on Beinn Ràtha (795 ft.) about two miles south-south-west of Reay. Measuring about a mile across from north to south, it

* *Op. cit.*, p. 391.

† Bighouse Bay appears as Melvich Bay in the 1912 edition of the Ordnance Survey Sheet 115.

comprises three zones, viz., a lower band of breccia and conglomerate, an intermediate one of grey and white sandstone, and an upper conglomerate, the coarse deposits being of local origin. The floor of the outlier is composed partly of crystalline schists and partly of granite. Each zone is overlapped in turn by a higher one, till the upper conglomerate rests directly on the gneiss and granite along the east and north-east margins of the outlier. In other words, the floor of the southern part of the outlier represents the side of a pre-Old Red Sandstone valley sloping westwards.

Northwards along the county boundary from Cnoc na Tobaireach to Beinn Ruadh (609 ft.) the basal conglomerates are to be found protruding through peat, the pebbles being formed mainly of granite, though the underlying platform there consists of gneiss. There is no continuous section showing the sequence from these conglomerates up to the strata so clearly displayed on the sea-cliffs between Sandside and Bighouse Bay. But from occasional exposures in the burns and in quarry holes it appears that the intervening beds are composed largely of yellow and buff-coloured sandstones with thin bands of breccia, sandy flags and shales, dipping to the north and north-north-west at angles from 10° to 15° .

Proceeding now to the shore section, we find that the fossiliferous bands of limestone, calcareous flags, and grey sandstones of Sandside Bay are overlain at Sandside Head by grey and blue flags with sun-cracks and worm casts, dipping north and north-north-west at from 10° to 15° . With their characteristic cream-coloured tint on weathered surfaces, they can be followed along the cliff for about a mile to Geodh' na Moine. Beyond that inlet grey sandstones are interstratified with the flagstones till we reach the Red Point, where the sequence is interrupted by portions of the old platform of crystalline rocks rising through the sediments. Three of these projections have here been mapped. The largest occurs at the Red Point and consists of flaggy quartz-biotite-granulites, invaded by massive, rudely-foliated biotite-granite which is intersected by acid veins. The two smaller exposures to the west are likewise composed of schists, pierced by red granite and pegmatite. The relations of the overlying sediments to the old floor at this locality have been well described by Sir A. Geikie.* The remarkable feature of these rocks is the peculiar granitic breccia with a strong calcareous cement, merging into a limestone, which rests unconformably on the granite and gneiss. This limestone was recorded by Sedgwick and Murchison in 1829, who called attention to its crystalline and cellular character.† The breccia is succeeded by sandstones and flagstones. Here and there the sediments are brought into conjunction with the old floor by small faults.

Westwards from the Red Point there is a succession of grey and blue flagstones with occasional intercalations of grey sandstone, dipping generally to the north-north-west at angles varying from 10° to 13° , till we reach the eastern headland of Bighouse Bay. Here the strata bend round and are inclined to the north-east and north-north-east at angles from 15° to 40° . On the east side of the bay there is a steady descending sequence of strata comprising grey false-bedded sandstones, grey calcareous flags, and two bands of limestone

* *Trans. Roy. Soc. Edin.*, vol. xxviii., 1877-78, p. 345.

† *Trans. Geol. Soc.*, second series, vol. iii., 1829, p. 132.

that differ completely in character from the calcareous mass forming the local base of the series at Red Point. The upper band, visible on the rocky beach about half-way between the head of the bay and the eastern promontory, is 6 ft. thick, has yielded fish remains, and resembles the bed of fossiliferous limestone at Sandside Harbour.

The crystalline schists and plutonic rocks reappear on the west side of Bighouse Bay, but it is highly probable that the Old Red Sandstone has here been brought into conjunction with the old floor by the great fault that runs down Strath Halladale to the sea. Reference ought also to be made to the faults occurring in many of the goes or inlets along the shore section between Bighouse Bay and Sandside.

J. H.

CHAPTER VIII.

OUTLIERS OF OLD RED SANDSTONE BETWEEN BIGHOUSE BAY AND THE KYLE OF TONGUE.

ALONG the north coast of Sutherland, west from Bighouse Bay, there are several outliers of Old Red Sandstone, viz., one at Portskerra, one at Strathy, three at Kirkatomy, five on the mainland near the Kyle of Tongue, and one on the islands near the mouth of Tongue Bay. Only two of these detached masses (Portskerra and Strathy) have yielded fossils, but these clearly prove that the strata containing them are merely a westward extension of the middle division of the system as represented between Reay and Bighouse. The others consist mainly, if not wholly, of conglomerates, which may reasonably be regarded as basement members of the same series. One is of special interest from the occurrence in the conglomerate of a suite of pebbles derived from various Cambrian zones to be found in place in the Durness and Eireboll districts. Many of the characteristic features of the larger outliers, especially the marked unconformability between them and the crystalline schists, have been recorded by Sedgwick and Murchison in 1829,* by Hay Cunningham in 1841,† by Murchison in 1858, ‡ and by Sir Archibald Geikie in 1878.§.

The small outlier on the headland north of Portskerra shows clearly the unconformable relations of the basement beds to the schists and plutonic igneous rocks, which are laid bare on the sea-cliffs and on the beach. Stack-like masses of schists and granite project through the sediments, indicating the uneven character of the old floor. The basal breccia, composed of the underlying rocks, is succeeded by yellow sandstones, inclined towards the north at low angles. Sir Archibald Geikie records that "in one of the pale sandstones, Mr. C. W. Peach found an ichthyolite, which was regarded by Professor Huxley as resembling *Glyptolæmus* of the Upper Old Red Sandstone of Dura Den." || Dr. Traquair informs us that the counterpart of this ichthyolite is in the collection of the Royal Scottish Museum, Edinburgh, and has been identified by him as *Thursius macrolepidotus*.

Of these isolated masses of Old Red Sandstone, the Strathy outlier is the most important, as it is the largest, and has yielded a small assemblage of Caithness fishes. On the shore it stretches eastwards from Strathy Bay to near Rudha na Cloiche—a distance of about a mile, and can be followed southwards for four miles to Beinn Ruadh (837 ft.). The general dip of the strata is towards the north-north-

* *Trans. Geol. Soc.*, second series, vol. iii., 1829, p. 130 et seq.

† *Trans. Highl. and Agric. Soc.*, vol. vii., 1841, pp. 105–106.

‡ *Quart. Jour. Geol. Soc.*, vol. xv., 1859, p. 403.

§ *Trans. Roy. Soc. Edin.*, vol. xxviii., 1877–78, p. 383 et seq.

|| *Op. cit.* p. 396.

west at angles from 10° to 18° , except near the southern limit where the inclination is north-west. As the base line of the sediments at the south end is just over 500 ft., and, on the shore, passes below sea-level, the dip is therefore mainly due to original deposition and not to subsequent tilting of the strata.

The basement conglomerate is well seen on Beinn Ruadh, where it contains granite blocks up to 3 ft. in diameter. About half a mile to the north, the conglomerate is followed by red arkoses and sandstones striking obliquely across the outlier, and these in turn are succeeded by a coarse conglomerate with included blocks, 4 ft. across. It likewise trends north-east and south-west, and is continued through Loch Baligill Hill to Creagan Réidhein. Next in order we find red, buff, and yellow sandstones with conglomerate bands, which extend northwards for two miles, and are well exposed in the Baligill Burn and in Allt an Réidhe Ruaidh.

In the Baligill Burn, about half a mile south from the main road between Thurso and Tongue, some bituminous shales are intercalated in buff-coloured sandstones and arkoses. There can be little doubt that these herald Caithness flagstone conditions. Near the mouth of the stream two bands of limestone appear, one of which (the lower one) has been quarried and burnt for lime. It can be traced along the sea-cliff east of the stream, where it is interbedded with calcareous yellow sandstones, to a point within a few yards of the local base of the outlier. And yet both bands can be followed inland in a south-westerly direction under the hamlet of Baligill, and the upper one to a point near Strathy Free Church, being overlain in that direction by calcareous flagstones, sandy flags, and thin grey and yellow sandstones amounting to several hundred feet in thickness. These overlying strata are admirably displayed on the sea-cliff that stretches westward to Strathy Bay, where they present many of the characteristic features of the Caithness flagstone coast scenery. In his description of this limestone, Sir Archibald Geikie notes that it is finely-striped by its laminae of deposit, along many of which lie numerous minute oval calcareous grains, and some large oval cavities filled with crystalline calcite.* He observed no organic remains in it, but the white calcareous bodies suggested to him the cyprid cases of other Palæozoic limestones, particularly that of Burdiehouse.

The fishes collected from the fossiliferous bands at Baligill have been determined by Dr. Traquair who has kindly supplied the following list:—*Thursius macrolepidotus*, *Cocosteus decipiens*, and *Dipterus macropterus*. The last of these forms is characteristic of the John o' Groat's division of the Orcadian series.

The junction of the Old Red Sandstone with the older rocks is not visible in Strathy Bay, being concealed by blown sand and alluvial deposits.

The isolated masses in the Kirkatomy district are composed mainly of conglomerates. The central outlier, about three-quarters of a mile east from Kirkatomy Bay, occupies a pre-Old Red Sandstone valley trending north-north-west, a large part of which is now drained by a streamlet that enters the sea not far to the east of Kirkatomy Point. The outlier forms a narrow strip from 200 to 400 yards in breadth, and about a mile in length, with a ridge of biotite-gneiss and granite

* *Op. cit.* p. 397.

on either side. At its southern end the base line of the conglomerate is about 500 ft. above sea-level, and, at its lower end, it occurs near the top of the sea-cliff below the 200-ft. contour line. In all the exposures along the old valley, the conglomerates and pebbly grits have a persistent dip to the north-north-west at angles of about 15° —a feature which must be due to original deposition rather than to subsequent tilting of the strata.

The outlier in Kirkatomy Bay covers a larger area, its length being a mile from north to south, and its extreme breadth about half that distance. The strata consist of conglomerates, made up of the debris of local rocks, and reddish-grey sandstones with intercalations of soft, red, sandy clay or marl. The conglomerates occur at the south end of the area; in the Kirkatomy Burn, where they are interstratified with sandstones; and also on Sgeir an Eilean, an islet near high water mark on the west side of Kirkatomy Bay. At the last of these localities the pebbles are well rounded and measure from 2 to 3 ft. in diameter. The general dip of the sediments, except in Kirkatomy Burn and on the sea-cliff to the west thereof, is towards the north-west at angles varying from 15° to 20° . The unconformable junction is admirably seen on the east side of Kirkatomy Bay, where the sandstones abut against a steep slope of the old rocks, composed of granulitic gneiss, biotite-gneiss, and granite. The western boundary of the outlier coincides, for a certain distance, with a line of fault.

Further evidence of the highly-eroded land surface on which the Old Red Sandstone was deposited is furnished by the detached masses near the Kyle of Tongue. The outlier of Cnoc an Fhreicheadain, which crosses the main road between Thurso and Tongue, trends nearly north and south, is about two miles long and half a mile broad at its northern limit, and is bounded by a fault along the west side. The general dip of the beds, with certain exceptions, is towards the north-west or westerly towards the fault.

At the base of the sequence we find a breccia, from 50 to 100 ft. thick, which occurs only at the south end of the area. It is composed mainly of subangular and rounded fragments of schist, but no granite boulders were observed in it. Next in order come red sandstones and marls from 300 to 400 ft. in thickness, visible in the burn west from Dalcharn. An interesting feature of the marls is the occurrence in them of nodules of limestone, resembling those in the well-known fish-bed in the basin of the Moray Firth. After a careful search no organic remains were found in them. These sandstones are succeeded by a mass of conglomerate, about 1000 ft. thick, which forms the northern half of the outlier and culminates in Cnoc an Fhreicheadain (1009 ft.). It differs from the basement breccia in containing boulders of granite like that of Beinn Laoghal as well as blocks of the local schists. The base of the series at the south end of the outlier is 400 ft. above O.D., and at the northern limit it descends to the sea-level. There must, therefore, be a general inclination of the floor towards the north.

About half a mile south-west from Cnoc an Fhreicheadain, a prominent hill (976 ft.) is capped with an isolated mass of conglomerate with layers of sandstone. The strata dip as a rule towards the north but at a higher angle than the base line of the conglomerate on the schists. The overlap of the unconformable sediments on the old platform is well seen from a point on the main road to Tongue, about

half a mile north of the hill. There can be little doubt that this conglomerate is merely an outlying portion of that on Cnoc an Fhreiceadain—a view which is supported by the occurrence of a small isolated patch of this rock midway between the two hills.

The detached mass of breccia and conglomerate on Beinn Bhreac, about half a mile east from Tongue, measures about a mile in length and about half a mile in breadth. The boundaries of the outlier are mostly concealed under morainic drift. Though the materials of which the rock is composed consist mainly of the local granulitic schists, well-rounded boulders of granite similar to that of Beinn Laoghal are to be found in it. It is evident that the conglomerate lies on a pre-Old Red Sandstone slope that dips to the west, for along the north-west margin the boundary is not far below the 900-ft. level, while on the western declivity it crosses the contour lines successively till the base line reaches about the 500-ft. level.

Still farther south, on Knock Craggie (1043 ft.)—a hill about two and a quarter miles south-south-east of Tongue village—another outlier of conglomerate has been mapped. Here again the uneven surface of the old floor is conspicuously shown by the behaviour of the boundary line of the mass, which crosses the 900-ft. contour line not far to the west of the hill top, and descends to the 600-ft. level at the base of the eastern declivity. And yet the strata, where dips have been recorded, are inclined to the west. The included blocks are composed of the local granulitic schists and a large proportion of granite similar to that of Beinn Laoghal. An interesting point connected with this outlier is the highly brecciated character of the floor on which it rests. The granulitic quartz-schists are traversed by innumerable joints a distance of 200 yards away from the base line of the conglomerate along the western margin. In places this brecciation is so pronounced that it is difficult to determine where the boundary line should be drawn.

The development of conglomerate on the three islands near the mouth of the Kyle of Tongue, viz., Eilean nan Ròn (246 ft.), Eilean Iosal, and Meall Halm, claims special attention on account of the variety of Cambrian pebbles in the conglomerate, which were discovered there in the course of the geological survey of the district. Sir Archibald Geikie, in his description of these islands, called attention to the fact that, though they nowhere show the junction of the sediments with the old crystalline schists, they furnish the most instructive series of sections in the Tongue district.* The strata consist of beds of conglomerate with frequent intercalations of red sandstone, and are inclined to the north-west or north-north-west at angles varying from 12° to 18° . Here and there, especially near fault-lines, the angle may rise to 38° . The pebbles vary in size up to 1 or 2 ft. in diameter, and are, as a rule, well-rounded while some are subangular.

The lowest rocks are exposed in the north-west corner of Eilean nan Ròn, where the conglomerates contain rounded pebbles of hornblende-granite, quartz-granulites, hornblende-gneiss, and hornblende-schist. Some of the granite blocks measure 18 ins. across. Not far to the south, at the mouth of Mol na Coinnle (the cove of candles), the included pebbles consist mainly of schist and granite, but boulders of Cambrian dolomite, up to a foot in diameter, like that of Durness,

* *Op. cit.* p. 383.

are also to be found. A similar assemblage with fragments of Cambrian dolomite occurs on the west side of the island, at the head of Mol Mòr.

Eilean Iosal is composed of coarse conglomerate with occasional intercalations of ribs of red sandstone. At the north-west corner of the island the conglomerate contains well-rounded stones, the largest about 2 ft. across. They are tilted to the north-west at an oblique angle to the bedding planes, as if brought to their present position by a current from that direction. The large blocks, over 1 ft. in diameter, consist of varieties of quartz-schist of the Moine series. Among the smaller pebbles a striking feature is the abundance of fragments of Cambrian dolomite and limestone, belonging to the Ghrudaidh, Eilean Dubh, Sangomore, and Croisaphuill groups of the Durness basin. The percentage of pebbles was taken at this locality with the following results:—

Moine Series.	{	Quartz-granulites	56
		Mica-schist	4
		Mylonised rocks	5
Cambrian.	{	Dolomite and limestone	24
		Serpulite Grit	1
		Pipe Rock	1
		Basement quartzite	1
? Cambrian.		Quartzite	5
Source uncertain.		White quartzite	3
			100

The small island, Meall Halm, is composed of similar conglomerates which dip to the north-north-west at moderate angles.

B. N. P., J. H.

CHAPTER IX.

LITHOLOGY AND CONDITIONS OF DEPOSIT OF THE CAITHNESS FLAGSTONE SERIES.

LACUSTRINE ORIGIN OF THE CAITHNESS FLAGSTONES.

THE Caithness Flagstone Series displays three main lithological groups :—

3. The John o' Groat's Sandstones; chiefly red and yellow false-bedded, friable sandstones.
2. The Flagstone Group proper; chiefly fine-grained, calcareous, and argillaceous flags with tints of bluish-grey, and black.
1. Red and purple mudstones and arkoses with breccias and conglomerates.

All the rocks are somewhat calcareous, but the flagstones are especially so. Red rocks are nearly confined to the lowermost and uppermost groups.

The John o' Groat's Sandstones resemble the Upper Old Red Sandstone of Dunnet Head. The lower group of red rocks has features in common with the Caledonian or Lower Old Red Sandstone. It is in the Flagstone Group proper that the lithological peculiarities of the Caithness Flagstone Series are chiefly displayed, and it is to the flagstones that Sir Archibald Geikie referred as follows :—

“Even a geologist whose eye has long been familiar with the Old Red Sandstone in more southern regions, finds at first some difficulty in believing that the dark shaly flagstones and limestones of Caithness and the Orkney Islands can form part of the Old Red Sandstone within the same geographical area in which red and purple sandstones are elsewhere so prevalent.

“In other tracts he is familiar with the general barrenness of the red sandy strata in regard to organic remains; but in these northern rocks he meets with layers which are crowded with well-preserved teeth, scales, and bones of fishes. Mere difference of lithological character does not necessarily point to difference of age, and certainly cannot be cited in favour of a threefold classification of the Old Red Sandstone.

“But this striking contrast in the nature of the strata does point to markedly dissimilar conditions of deposition. The Old Red Sandstone of the north of Scotland must have accumulated in a distinct geographical basin and under circumstances to which as yet no parallel has been found in the Old Red Sandstone of other parts of Britain.” *

The Lower Old Red Sandstone followed a period of continental extension and mountain building, but it has been shown by Suess

* “On the Old Red Sandstone of Western Europe,” *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 363.

that the laying down of the Middle Devonian was attended by an extensive marine transgression.*

The period of formation of the Caithness Flagstones would therefore coincide with the greatest submergence of the Old Red Sandstone continent, and it is in association with them we should have expected marine deposits intercalated with those of more normal Old Red Sandstone facies.

So far as the Caithness deposits are concerned, no marine origin can be entertained. The lithology and palæontology equally bear out this contention. The ill-sorted and yet finely laminated fine-grained deposits, the absence of beach deposits, and the constant recurrence of mudstones with well-defined sun-cracks in rapid alternation with calcareous flags through thousands of feet of strata, cannot be explained on the assumption of any marine hypothesis. Sun-cracks sometimes occur in the mud of estuaries where the tide is of great vertical range, as in the Bay of Fundy, and also under other limited geographical conditions, but the marine deposits thus formed are more uniform in nature, and differ widely from the rapid alternations of contrasting deposits of the Caithness Flagstone sequences.

In Russia deposits with Old Red Sandstone fish remains are intercalated amongst Devonian rocks with marine fossils. Such alternating continental and marine deposits may be explained as having been formed near sea-level, where at one time the delta deposits of rivers, at others marine sediments, were laid down over the same areas, owing to inequalities in the ratio between subsidence and sedimentation. They were formed along the coast-line of the Old Red Sandstone continent, during the encroachment of the Devonian sea, but there is no evidence that even at the height of the Middle Devonian transgression the sea invaded the area where the Orcadian strata are now exposed for our examination.

The fossils of the Caithness Old Red Sandstone represent the remains of ancient terrestrial plants and fish with the little crustacean *Estheria membranacea* and the gigantic eurypterid *Pterygotus*. No undoubted marine fossils have been met with, and in reference to this it must be clearly understood that the chance of marine organisms having been originally present and completely destroyed during the formation of the deposits, or subsequently by solution, is practically nil. Marine limestones widely formed in the Devonian seas during Orcadian times are replete with the remains of corals, encrinites, brachiopods, and other organisms, and it may be taken for granted that had there been any solution of the remains of such a marine fauna as would have existed where lime was so abundant as in the Orcadian waters, casts of some of the forms would have remained to mark their former presence.

But can any of the fossils actually found be considered as marine?

The plants are certainly land plants, but might have been washed seaward. A large number of the fossil fish are confined to the Orcadian deposits, a fact which in itself assumes some degree of faunal isolation, as pointed out by Sir Archibald Geikie,† and is therefore against the marine hypothesis. Species belonging to some of the groups of fishes found in the Old Red Sandstone have certainly been found in marine

* *The Face of the Earth*, vol. ii. pp. 229, 539.

† *Op. cit.*

deposits, but this of itself is of no value to the argument that the Old Red Sandstone deposits are marine in origin.

But important palæontological evidence is afforded by the abundance of *Estheria membranacea* in some of the higher beds of the Caithness Flags. According to Rupert Jones, the twenty-two living species of *Estheria* are found in stagnant pools and marshes, temporary rain-pools, and occasionally in brackish water, in all six continents, but marine forms have never been found. Fossil *Estheriæ* are found in association with *Anthracosia* in the Coal Measures, with *Apus* in the Permian, with insects in the Rhætic, and with *Cyrena* in the Wealden, an assemblage which sufficiently stamps the land-locked and fresh-water habitat of the genus in the past. *Estheria* is found with *Lingula* in the Old Red Sandstone of Livonia, and with *Spirorbis* in the Trias of Germany, but both *Lingula* and *Spirorbis* are the marine forms of the Palæozoic deposits most often found in association with fresh-water species. The association in these cases was probably induced by the capability of the species of living in brackish water, an abnormal habitat for either of its associates.

Professor Rupert Jones states his conviction that *Estheria* is as distinctive of land-locked waters in the past as it is at the present time.*

The lacustrine theory of the origin of the Old Red Sandstone has long had a wide acceptance amongst geologists. Formulated in 1855 by Godwin-Austen,† the view was further elaborated by Sir Archibald Geikie.‡

The latter author distinguished five basins of deposit to which he gave the names now generally adopted. The Middle Old Red Sandstone of Caithness forms part of "Lake Orcadie" in which he included all the Old Red Sandstone deposits north of the Grampians, those of the Moray Firth area, of Caithness, Orkney and Shetland, and of various outliers in the interior of Ross and Sutherland, and along the north coast of Sutherland as far west as Tongue.

Geikie laid great stress on the unevenness of the old floor on which the Old Red Sandstone rests, and was the first to point out the great overlap between the Ord and Reay. He considered a continuance of the crustal movements, which heralded the formation of the Old Red Sandstone, as sufficient to account for the enormous thickness of sediment laid down in this inland sea.

CLIMATIC CONDITIONS.

In discussions on the Old Red Sandstone and formations of similar lithological characters, attempts have been made to deduce the climatic conditions of deposition from the nature of the rocks. The decomposed or fresh state of the feldspars occurring in sedimentary rocks has been considered a good index to the climatic conditions which prevailed during deposition.

Goodchild thought that the fresh state of the feldspars in the Old Red Sandstone suggested arid conditions.§

Later, Dr. Mackie showed that the Caledonian deposits yield

* "Monograph of the Fossil Estheriæ," *Monog. Palæont. Soc.*, 1862.

† *Quart. Jour. Geol. Soc.*, vol. xii., 1855, p. 38.

‡ *Op. cit.*

§ *Trans. Edin. Geol. Soc.*, vol. vii., 1896, p. 203.

70-80 % kaolinised felspars, while the Orcadian deposits for the most part yield 70-90 % fresh felspars. From this he inferred that during the formation of the Orcadian deposits a glacial or subglacial climate prevailed, while during the deposition of the Caledonian Old Red Sandstone, milder conditions were prevalent and chemical agencies were the chief rock disintegrators.*

It is very improbable, however, that glacial conditions existed in the immediate surroundings of Lake Orcadie, since nothing of the nature of glacial erratics has been discovered in the flagstones.

The red colour of many of the Old Red Sandstone deposits, and the nature and origin of the bituminous flagstones and limestones of Caithness have also formed a basis for speculation. As long ago as 1871, Ramsay advanced the hypothesis that red deposits were formed in salt lakes.†

Goodchild also compared the Caithness Flagstones to the deposits being laid down in the Dead Sea or the Salt Lake of Utah, and considered the bituminous matter of the flagstones as due to the decomposition of plant remains in the presence of sulphate of lime, with a resulting formation of bituminoids and the precipitation of carbonate of lime.‡

There are, however, no salt or gypsum deposits known from the Old Red rocks of this country, and the abundant fish fauna of the Caithness flags is strongly against the view that the rocks were formed in salt lakes.

CLASSIFICATION OF THE DEPOSITS.

The Orcadian strata of Caithness may be arranged in three main groups according to the conditions under which we believe them to have been formed—

1. Subaerial deposits marginal to and underlying the lacustrine deposits of Lake Orcadie and due to local erosion and subaerial accumulation.
2. Lacustrine, delta, and flood-plain deposits of the waters of the river system forming the main supply of Lake Orcadie.
3. Subaerial deposits intercalated in the lacustrine deposits.

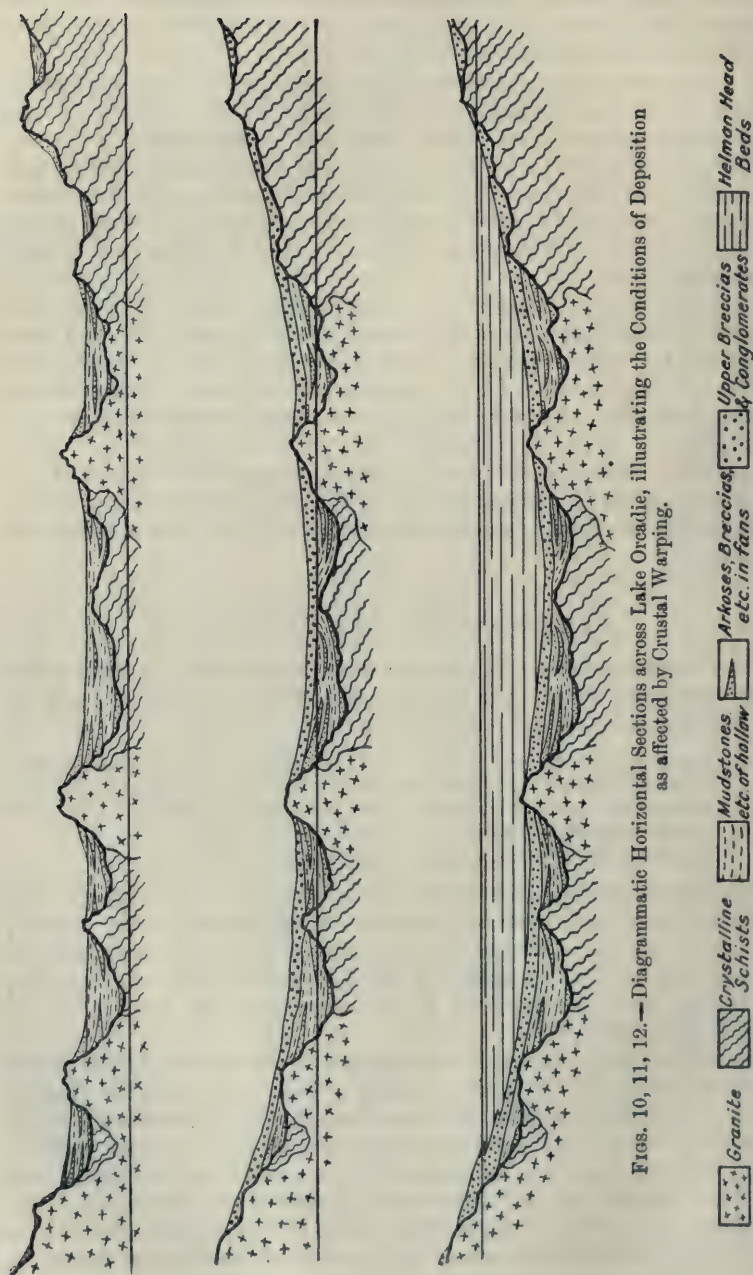
The first occupied the slopes and hollows before subsidence, and accumulation of sediments led to their being buried by the second, while the third were formed during more or less prolonged retreats of the waters of Lake Orcadie, by the advance of marginal deposits, and through the rearrangement of the deposits of the flood-plain by waters of local derivation.

Fig. 10 is a diagrammatic horizontal section of the marginal deposits towards the close of the period during which the basement fringing breccias and conglomerates and the barren red arkoses and mudstones were formed as subaerial deposits. Mudstones and arkoses fill the hollows, and fans of coarser arkoses and breccias spread out from the slopes. A line shows the hypothetical surface of Lake Orcadie at this period, since it is probable that lacustrine conditions had commenced in the Orcadian basin previously to the formation of the first flagstone strata of which evidence is obtainable.

* *Trans. Edin. Geol. Soc.*, vol. vii., 1898, p. 443.

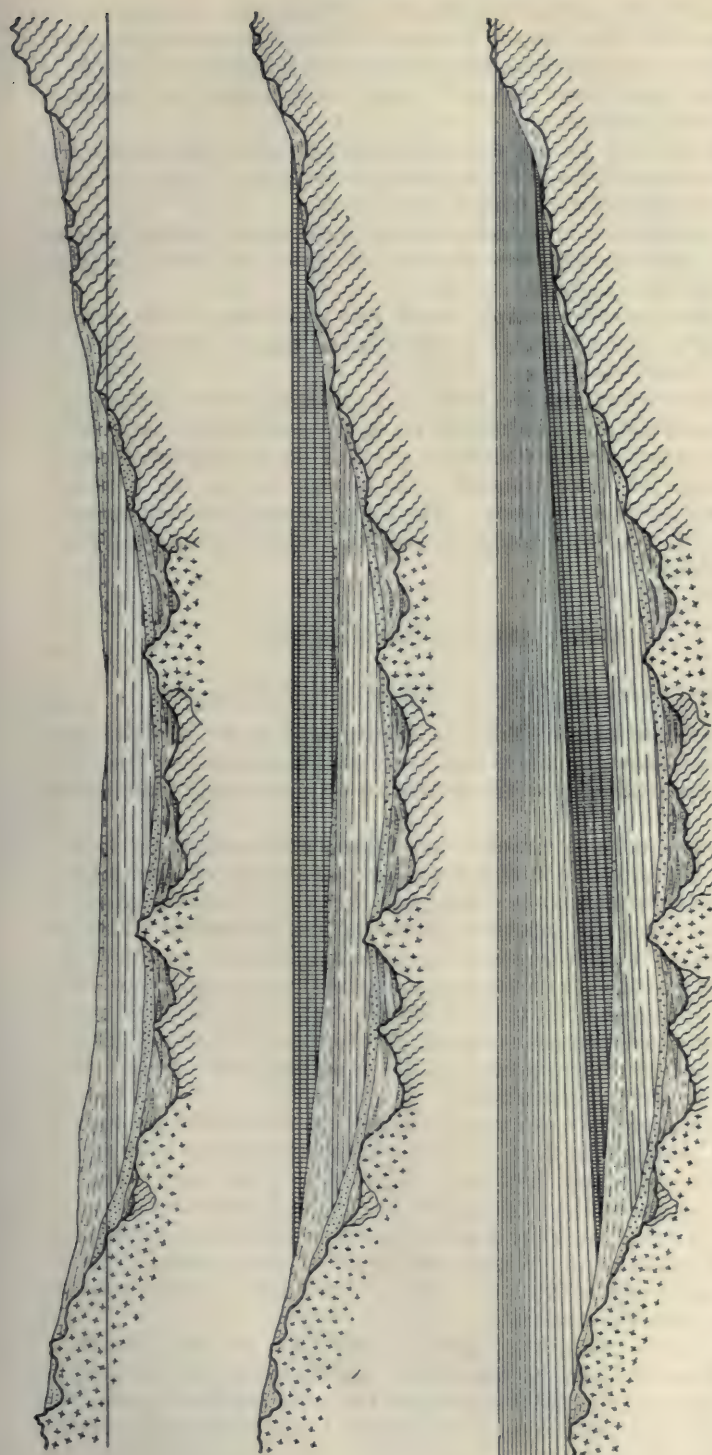
† *Quart. Jour. Geol. Soc.*, vol. xxvii., 1871, p. 241.

‡ *Proc. Roy. Phys. Soc. Edin.*, vol. xiii., 1897, p. 316.



Figs. 10, 11, 12.—Diagrammatic Horizontal Sections across Lake Orcadie, illustrating the Conditions of Deposition as affected by Crustal Warping.

Explanation to Figs. 10, 11, 12.



FIGS. 13, 14, 15.—Diagrammatic Horizontal Sections across Lake Oreskoe, illustrating the Conditions of Deposition as affected by Crustal Warping.

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Explanation to Figs. 13, 14, 15.

Fig. 11 shows the period of formation of the upper conglomerates and breccias of Badbea, Morven, Ellens Goe, etc. Crustal warping has led to tilting and partial denudation of the previously formed deposits, and the surface was widely covered by the torrential fans now forming breccias and conglomerates.

Fig. 12 shows how further down-warping has led to the encroachment of the waters of Lake Orcadie, and represents the close of the period of formation of the Helman Head Beds.

Fig. 13. Differential subsidence has led to the retreat of the waters of the lake, and subaerial deposits are laid down to form the Red Beds of Brough and Lybster.

Fig. 14. Further down-warping leads to a readvance of the waters of Lake Orcadie, and this stage represents the close of the period of formation of the Wick Flags.

Fig. 15. Further subsidence leads to a great extension of the lake and a great overlap of its sediments on to the foundation crystalline rocks. This stage represents the close of the Thurso Flagstone period.

The deposits of Lake Orcadie were formed during the gradual subsidence of a continental basin. The warping was doubtless accompanied by trough faulting, though no definite evidence of such faulting has been detected.

BASEMENT AND MARGINAL DEPOSITS.

1. *Local Basement Arkoses, Breccias, and Conglomerates.*

About the oldest known Old Red Sandstone deposits in Caithness are the coarse arkoses of the Ousdale district, which rest on the Ord granite, and were directly derived from it by mechanical disintegration.

The minerals of both granite and arkose are surprisingly fresh, and those of the arkose for the most part so devoid of orientation that it is often very difficult to distinguish the arkose from the granite. Passing inland along the junction of the Old Red Sandstone with the underlying rocks, until it leaves the granite and steps on to the crystalline schists, we find that the coarse arkose rapidly gives place to breccias or conglomerates of subangular fragments of schist and granite. Coarse arkoses again appear in the districts north of Braemore and south of Reay, where granite forms the floor to the Old Red Sandstone at higher horizons.

The local basement rocks vary in composition with the character of the rock forming the floor, and also according to the inclination of the surface on which they rest. Thus where quartzite forms a sloping floor on the flanks of Scaraben, the basal deposits consist of a breccia of small angular white fragments of quartzite exactly resembling those of the present screes on the slopes of the mountain. The fragments are cemented by an extremely fine-grained, white matrix also derived from the quartzite.

The hills in the ancient topography buried beneath the Old Red Sandstone deposits appear to have been chiefly granite and quartzite. We may therefore safely assume that the coarse arkoses and quartzite breccias were formed as screes and taluses, and were afterwards buried in the stratified deposits.

The valleys in the buried topography generally overlies mica-schists and quartzose schists, and their basal deposits are usually conglomerates of subangular fragments, including various types of schist, gneiss, quartzite, and granite. The stones vary much in size and in the amount of attrition to which they have been subjected, and the material is never a well-rounded and assorted shingle, like beach deposits. Large subangular boulders of granite and gneiss lie side by side with angular fragile slabs or thin plates of schist. Many of the subangular stones are often slightly concave on their sides, but are only in this respect suggestive of glacial or wind-eroded fragments. In no case were striae detected on them, except such as might be accounted for by pressure of one stone upon another at a date later than the formation of the rock; nor were any polished or faceted stones, definitely pointing to wind erosion, encountered. The matrix of these conglomerates is a fine-grained red arkose or mudstone, and where conglomerates are absent, fine-grained arkoses or mudstones rest directly on the crystalline rocks.

2. *The finer Deposits of the Hollows; Subaerial Fans and Flood Plains. The Arkoses and Mudstones of the Barren Group.*

Overlying the coarse arkoses of the Ousdale district and the basement breccias and conglomerates as far north as Shurrery, lies a thick mass of barren mudstones and fine-grained arkoses of a prevailing red or chocolate colour. The mudstones are excessively fine-grained, so much so that even a high power of the microscope fails to resolve their mineral constituents. Their finely-laminated character is brought out on weathered surfaces, but they rarely split with the regularity that is so characteristic of the true flagstones. Their red colour is sometimes replaced by a pale bluish-green, either in an irregular manner or in definite bands of green rock. With them are associated pale pink very fine-grained sandstones, which are calcareous, and weather with a honeycombed surface. Sun-cracks and other surface markings are not common.

3. *Basement Arkoses and Mudstones at Higher Horizons.*

Red mudstones, arkoses, and breccias are the prevalent types of rock in the outliers of Old Red Sandstone in the interior of Sutherland and Ross, where some of the remnants which have escaped denudation may consist of marginal subaerial deposits of later date.

A common type of deposit in these outliers consists of red mudstone with thin layers and lentils of coarse arkose grit, an admixture which points to rapid changes in the velocity and direction of currents, such as are found in ephemeral streams, or to deflation by the wind during accumulation. One of the most striking features of these deposits is their character of closely combining very fine-grained and excessively coarse-grained materials. While the fine-grained mudstones are usually but slightly fissile, the coarser arkose grits are often finely laminated, the weathered surfaces of the laminae showing a curious resemblance to oatmeal from the marked variation in the roundness or angularity of the grains, and from the fine powdery material which forms the matrix. These phenomena suggest some

degree of wind accumulation and deflation, and an absence of marked aqueous sorting of the materials during deposition.

4. *The Upper Breccias and Conglomerates ; Torrential Shingle Fans.*

In the Langwell Forest the mudstones are abruptly limited above by an unconformable junction with an overlying mass of breccia and conglomerate in the sections exposed as far apart as Badbea, Creag an Turnail, Achnavish Hill, and Cnocan Conachreag. At these places the breccia is covered by a thick mass of arkose. In the Sarclet region the mudstones pass up into the thick mass of arkose which forms Ulbster Hill, and this is covered by the Upper Conglomerate of Ellens Goe. The fragments of crystalline rocks and of felspar in these breccias and arkoses are as fresh as those in the basement arkose of Ousdale. These breccias and conglomerates, from their mixed origin and the finely laminated beds on which they lie, were formed from rock fragments carried some distance. Though of comparatively local derivation, the materials which form them have been carried considerable distances over very finely laminated deposits, and this points to some temporary acceleration in local erosion and transport. The unconformity at the base of the breccias in the Langwell Forest suggests crustal movements as the cause of this acceleration.

5. *The Nature of the Margin of Lake Orcadie during the Formation of the Flagstones.*

Marginal deposits proved to belong to the later stages of Lake Orcadie are rarely seen, but one or two exposures of the unconformity of the higher flagstones on the crystalline rocks afford sections of much interest. At Red Point, near Reay, flagstones several thousand feet above the basement beds come to rest against the gneiss. The finely-laminated and even-bedded character of the flagstones is continued right up to the edge of the granite and gneiss. A few feet from the vertical junction, small, highly angular fragments of granite and chips of fresh felspar lie scattered in the muddy sediment. They were evidently dislodged by subaerial flaking of the rock, and, falling into the mud, remained undisturbed exactly where they fell. There was nothing here of the nature of a beach, nor was there any tidal scour.*

In one of the sections at Red Point, on a sloping platform of granite forming a notch in the rocky wall, an extraordinary mass of tufa limestone is exposed. It rests on a lenticular mass of breccia, consisting of angular fragments of granite and gneiss set in a matrix of tufa. The breccia is 4 ft. thick, but thins out towards the edge of the platform. The overlying limestone is 12 ft. thick near the back wall of the notch, but thins out rapidly to less than 4 ft. in the same direction as the underlying breccia. Its upper surface, therefore, forms a steeply inclined slope. The limestone has a finely crystalline character and is laminated, the laminae being somewhat corrugated and steeply inclined like the surface of the deposit. They are given greater defini-

* For a description of similar phenomena in Orkney, see Flett, "Old Red Sandstone of the Orkneys," *Trans. Roy. Soc. Edin.*, vol. xxxix., 1898, pp. 392-407.

tion by included organic matter, and appear in section as wavy black lines, but the weathered surface of the deposit is extremely rough in the manner characteristic of tufa deposits.

Overlying the tufa limestone at the top of the section is a remnant of a second breccia 6 ft. thick, consisting of angular fragments of granite and gneiss set in a matrix of arkose and small fragments of the calcareous tufa. Tufa deposits are also known from other localities, at Dirlot, Achvarasdal, and Reay, where the base of the Old Red Sandstone is exposed. At Dirlot the laminae of deposit are very irregular and sometimes form a botryoidal mass. At Achvarasdal the tufa is very thick and finely laminated like that at Red Point, and the exposure is sufficiently extensive to have been quarried as a source of lime.

It is evident from the nature of these tufa deposits and of their lamination and concretionary character, that they were formed subaerially. The section at Red Point, with the breccia of mixed rock fragments above and below, suggests the action of a small water-course which occasionally swept down loose fragments of rock and at other times deposited tufa from highly calcareous waters.

LACUSTRINE AND FLOOD-PLAIN DEPOSITS OF LAKE ORCADIE.

Above the upper breccias and conglomerate of Badbea, Ellens Goe, etc., appear the Helman Head Beds and Berriedale Sandstones and Flagstones, the first deposits with bands rich in organic matter and lime. Red and green mudstones are, however, intercalated with the darker beds towards the base, and predominate in the Berriedale area. Flags, black with organic matter, and limestone bands appear earlier in the sequence in the Sarclet area than near Berriedale; in other words, marginal deposits make up the greater bulk of the beds in the Berriedale region.

The disappearance of the red colour in the rocks is everywhere associated with the presence of much organic matter and lime, and it is in strata of this nature that the first traces of fossil fish are found.

The Wick Flagstone Group.

The Helman Head Beds.—In the Helman Head Beds (Plate III.) we find for the first time a constant recurrence of certain phases marking very different conditions of sedimentation.

The sequence consists of dark limestones, pale sandstones, and greenish-white mudstones, repeated again and again and broken at intervals by thicker masses of black flags.

Sedimentary rhythm in marine deposits usually depends on the principle of the development of calcareous and terrigenous strata from opposite directions to overlap one another, owing to alternating periods of quiescence and movement in the crust.*

In the Helman Head Beds the rhythmic sequence is confined to continental, alluvial, and lacustrine deposits, and has resulted from variations in the height of the flood-water level on the one hand, and

* Edward Hull, "On Iso-diametric lines as means of representing the Distribution of sedimentary clay and sandy strata as distinguished from calcareous strata, with special reference to the Carboniferous Rocks of Britain," *Quart. Jour. Geol. Soc.*, vol. xviii., 1862, p. 127.

from a recurrence of periods of quiescence and crustal deformation on the other.

As an example of the sedimentary rhythm in the Helman Head Beds, the following measured section from near Helman Head is given. (Fig. 16.)

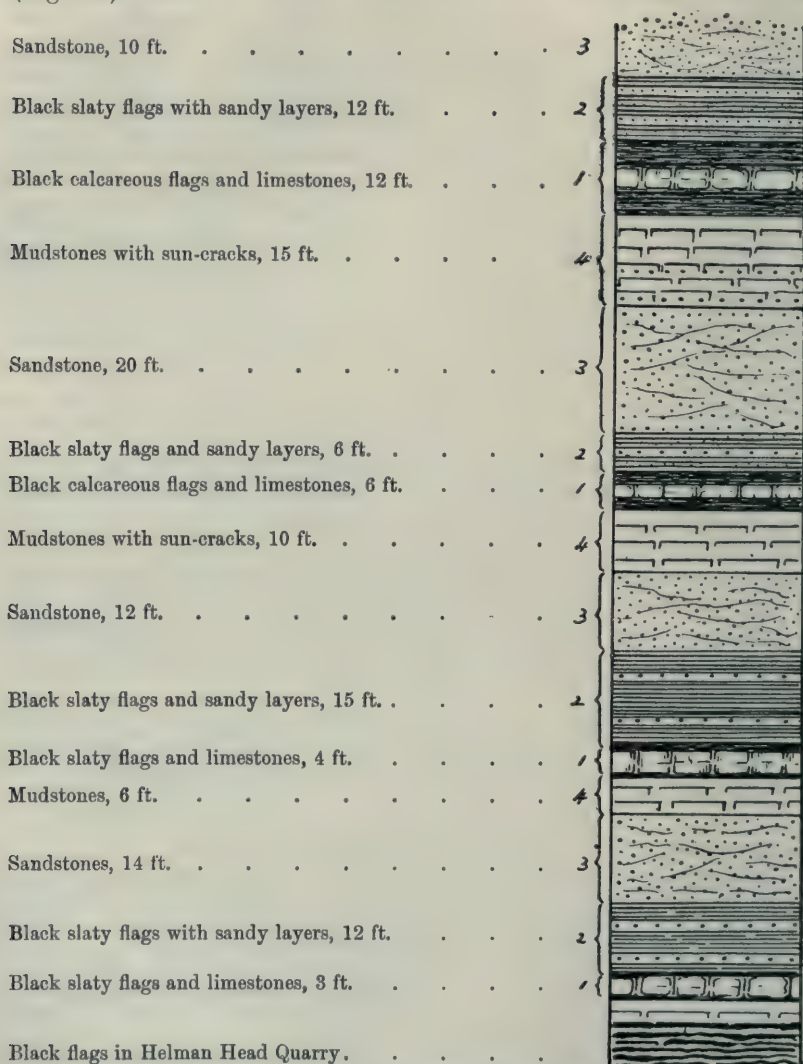


FIG. 16.—Vertical Section of part of the Helman Head Beds, to illustrate the type of Sedimentary Rhythm.

The limestones and associated slaty flags are perfectly smooth on their bedding planes. The slaty flags contain pyrites in the form of minute grains, and weather into pitch black, papery shales with alum. Sun-cracks and ripple marks are found in the intervening shales and sandstones. Bands of black flags, such as those worked in Helman Head quarry, occur at longer intervals than in the later formed Wick Flags. The sandstones are grey, fine-grained, and rather false-bedded.

The Red Beds of Wick and Lybster.—At length a change took place as sediment of a red colour again appeared and accumulated to a thickness of several hundred feet to form the Red Beds overlying the Helman Head Beds in the sections south of Wick and north of Lybster. These Red Beds consist of red mudstones and sandstones and sandy flags, and resemble the Berriedale Flags rather than the Mudstone Group proper.

The Red Beds probably represent subaerial deposits intercalated in the lacustrine sequence.

The Wick Flags.—With the Wick Flags much organic matter and lime again appear in the form of dark flags and limestones, and the rhythmic type of sedimentation is restored. The strata resemble those of the Helman Head Beds, but sandstone bands are less frequent, and mudstones are largely replaced by thick groups of coarse dark flagstones. Limestones are well-developed and contain abundant fish remains.

The flagstones are massive, dark with organic matter, and with abundant micas along certain layers. Their surfaces are uneven and covered with characteristic surface markings. Coarse ripple-mark is common, and shows a remarkable sameness of orientation (north-west to south-east), over a vast thickness of strata. Some of the surface markings are elongated (often 4 ins. or more in length), slightly curved and pointed at the ends. In certain cases they may be original, and are evidently what have been suggested as formed by fishes moving over the muddy bottom. Many, however, are obviously due to the puckering of the laminae of deposit after burial and perhaps at a much later date.

Other markings are rounded, flattened, and raised above the surrounding micaceous laminae. They vary from $\frac{1}{2}$ to 1 in. in diameter, are black with organic matter, and appear to be derived from plant fragments, since traces of a woody structure can sometimes be made out with a lens. There are also sandy knobs and pipes traversing the laminae of deposit which may be the work of burrowing annelids or due to the disturbance from escaping bubbles of gas.

The Passage Beds and Thurso Flags.

The Papigoe Beds.—In the Papigoe Beds the regular rhythm of sedimentation is continued, but the limestones become prominent from their comparative thickness and purity. Sandstones are less often met with. They are associated with, and often quite supplanted by, pale bluish-green calcareous flags and mudstones, the latter with well-marked sun-cracks.

The following sequence showing the rhythm of sedimentation is taken from the shore section near Papigoe. (Fig. 17.) It is in the Papigoe beds that the pale bluish-green, calcareous flags that bulk so largely in the Thurso Flagstone Group first appear. *Coccosteus diciptiens* also appears for the first time.

In the Thurso Flagstone Group the pale calcareous flags supplant the dark flagstones of the Wick type, and smooth calcareous flags of a blue colour with fish remains replace the dark slaty beds and limestones.

All the beds generally become so alike in colour that the sedi-

mentary rhythm so characteristic of the Wick Flagstone Group appears at first sight to be wanting. Close examination shows that the rhythm exists, but that the differences between the different members of a sequence are obscured by the predominance of fine argillaceous material.

The great mass of pale flags of the Passage Beds and the Thurso Flagstone Group is, however, interrupted by groups of markedly different character in which the rhythm is generally very distinct. These groups are the Field Beds, Noss Beds, Ackergill Beds, and Mey Beds.

The Field Beds.—The Field Beds point to a local or temporary

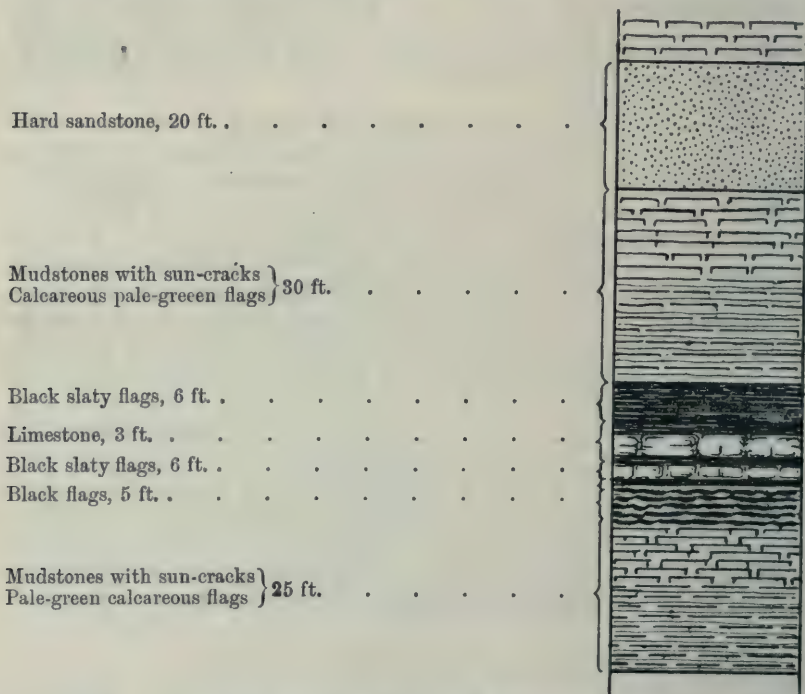


FIG. 17.—Vertical Section of part of the Papigoe Beds, to illustrate the type of Sedimentary Rhythm.

return of the conditions which led to the formation of sandstones and black slaty beds so characteristic of the Wick Flagstone Group. The slaty beds are, however, more bituminous and less calcareous, and yield fish remains of the same species as the Papigoe Beds. The mudstones associated with them are very pale in colour, and show well-developed sun-cracks. Sandstones are prominent, fine-grained, false-bedded, or ripple-marked.

The following characteristic sequence shows the rhythm of sedimentation which is repeated for a thickness of about 500 ft. It is taken from the shore section north of Field. (See Fig. 18.)

The Noss Beds.—This type is best exposed in the shore sections at Noss Head (Plate V., 2), Holborn Head, and at Forse, south of Lybster. The Noss type differs from all other lithological types of



1. NODULE-BED IN MEY FLAGS. Clairdon Shore, east of Thurso.



2. SUN-CRACKS IN MUDSTONE. Clairdon Shore, east of Thurso.

sedimentation in Caithness in showing a rapid alternation of very thin bands of very dissimilar character. Thin partings of yellowish ripple-marked sandstones, black flags full of organic matter and rough with surface markings, thin bands of black limestone weathering with a yellow crust, and pale greenish mudstones, alternate in rapid succession. The limestones are lenticular, and occasionally show a ripple-marked surface. The mudstones often show small sun-cracks. The surface markings of the black flags resemble those in the higher part of the *Thurso Flagstone Group*. They weather out on the surface like a "repoussé ornament," as described by Flett in his account of the *Rousay Beds* of the *Orkneys*.*

This type of surface marking has not been observed in the *Wick Flagstone Group*. The lithological characters of the *Noss Beds* point

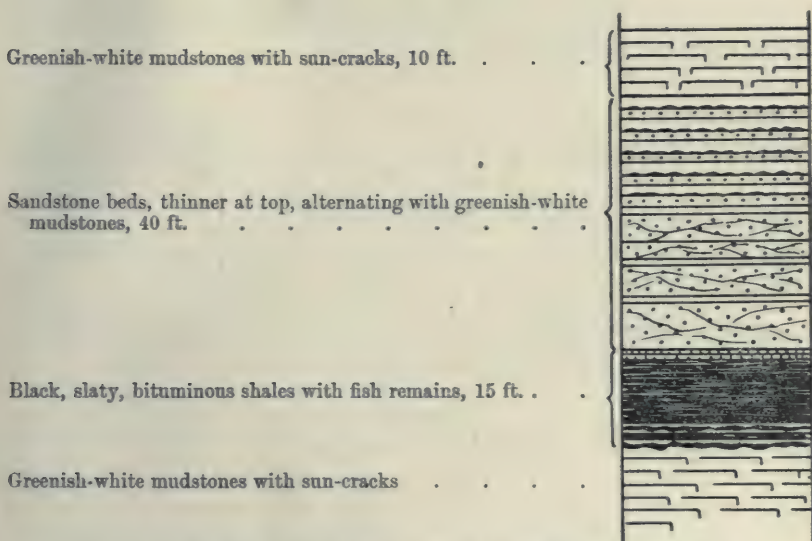


FIG. 13.—Vertical Section of part of the *Field Beds*, to illustrate the type of *Sedimentary Rhythm*.

to very shallow water conditions and rapid changes in the strength of the sediment-laden currents.

The Ackergill Beds.—Beds of *Ackergill* type are exposed in the shore sections at *Ackergill*, *Keiss*, *Freswick*, and at *Forse*, south of *Lybster*.

They consist largely of grey, yellow, brown, purple, and red sandstones, some of which pass into "nodule beds" consisting of rounded masses of hard sandstone set in a sandy matrix. The bands of sandstone are very variable in thickness, and are associated with greenish, lilac, and purple papery shales and mudstones with sun-cracks, and hard, strongly bituminous lead-blue and black shales which frequently have distorted bedding like oil-shales, and contain small fragments of fish and plants.

The following sequence characteristic of the rhythm of sedimenta-

* "Old Red Sandstone of the *Orkneys*," *Trans. Roy. Soc. Edin.*, vol. xxxix., 1898, p. 406.

tion is taken from near the Ackergill Lifeboat Station. (See Fig. 19.)

Fragments of plants are commoner in the Ackergill Beds (and the Mey Beds) than in any other beds of the Caithness Flagstone Series. The sandstones are false-bedded and sometimes gritty and approach the John o' Groat's Sandstones in appearance. The black bituminous shales are far less calcareous and relatively much richer in finely divided plant debris and argillaceous matter than the slaty-black limestones of the Wick Flagstone Group. The fish remains are always fragmentary, and contrast with the whole fish so commonly found in the black slaty limestones.

The Ackergill Beds were, perhaps, formed on parts of the lake bed which for long periods remained somewhat lower than the general surface, and when the waters retreated, acted as channels which drained the mud-flats, or they may represent the position of deltas formed during such periods.

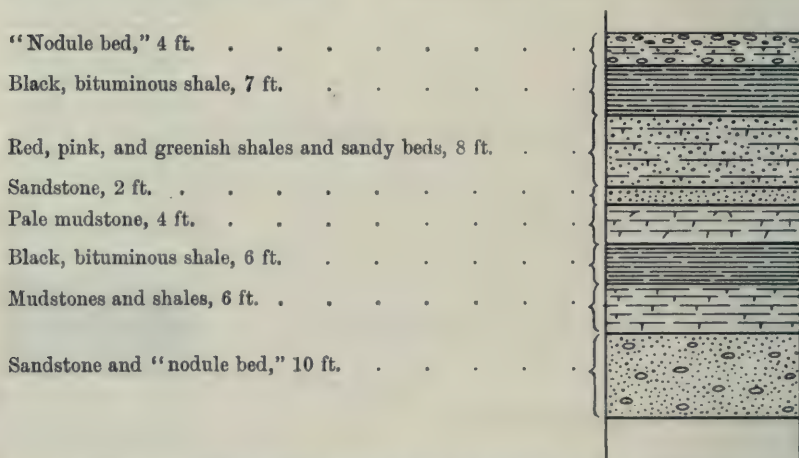


FIG. 19.—Vertical Section of part of the Ackergill Beds, to illustrate the type of Sedimentary Rhythm.

The gritty and false-bedded nature of the sandstones and the lack of the usual cemented character of the flagstones suggest that the beds were formed under the influence of gently flowing waters. The greater amount of plant debris, the fragmentary condition of the fish remains, and the greater degree of sorting of the deposits, all point in the same direction.

The black bituminous argillaceous shales formed where lime failed to precipitate. In the deltas or channels of the mud-flats lime would fail to settle, while plant debris would slowly accumulate and become mixed with muddy sediments. Much of the organic matter might be derived by erosion and washing of the organic limy deposits formed during periods of higher water-level.

The Mey Beds.—With the incoming of sandstone bands in the higher part of the Thurso Flagstone Group, the sequence assumes a definite repetitive character of easy recognition. This type of sedimentation is described under the name of Mey Beds from the coast line at Mey where it was first noticed.

The following sequence showing the rhythm of sedimentation is, however, taken from the equally characteristic coast section between Thurso and Castletown. The sequence is given in ascending order.

1. Dark blue-grey calcareous flags with smooth bedding planes and abundant fish remains weathering pale blue. The flags weather a variety of colours from yellow to pink and blue. The beds mark the deepest water conditions in the sequence.

2. Paler flags with numerous small sandy inclusions projecting on weathered surfaces and often so abundant as to form a raised net-work or "*repoussé* ornament." The inclusions are elongated, and taper at the ends and sometimes cross one another to form stellate patterns. The same inclusions occur in the overlying beds with sun-cracks. Where thin beds of sandstone are intercalated in the flags, these bodies form a raised net-work on both the lower and upper surfaces of the sandstone beds. In the flags they are more numerous in particular laminae, but occur throughout their thickness. From their mode of occurrence there seems to be a close connection between these elongated and star-shaped sandy inclusions and the sandy material which fills the sun-cracks in the overlying beds. Their form often suggests that the mud, after drying and cracking, was again disturbed by the water, and the partly cemented sand in the sun-cracks broken into small fragments and distributed in the mud. In some cases the inclusions are more calcareous than sandy, and appear to have been tubular as they show a darker core in section. These forms end in a blunt knob and appear like concretions round some body which has decayed. Small nodules of marcasite are common in these beds.

3. Very pale greenish mudstones with large sun-cracks and thin layers of sandstone with ripple-marked surfaces. The sandstone layers are often rapidly repeated and then generally show ripple-mark with different orientation. The direction of the ripples in one layer may be at right angles to that in a succeeding layer only 3 or 4 ins. above. The breadth of the ripples varies, but it is usually less than 2 ins. from furrow to furrow. The ridges and furrows are very elongated, and the ridges tend to anastomose to a greater degree than the furrows. This kind of ripple-mark resembles that often seen on the sandy bottom of lakes where the water is very shallow, and is caused by agitation of the water, from wind blowing over the surface. The varying orientation points to a changeable wind or to the water being so shallow as to be agitated to the bottom by winds from several quarters.

The sun-cracks in the mudstones are often 3 to 4 ins. wide, and form polygons sometimes having a diameter of 2 ft. or more (Plate VI., 2). They are generally filled with sandy material which may often be seen in continuity with overlying thin sandstone layers. In many cases, however, they are filled with a kind of breccia of small, curved, thin fragments of calcareous shale having a yellow colour. These fragments may be 1 in. in diameter, but are usually much smaller. Thin layers of a similar material are often found as laminae on the surfaces of the mudstone bands, and sometimes descend into the cracks and line their

sides. The curved fragments as suggested by Geikie,* are evidently derived from a thin pellicle on the mud drying, cracking, and curling up. Sun-cracked beds are sometimes seen with the polygons elongated in a definite direction, suggesting stretching of the deposits.

4. Sandstones which are fine grained, pale yellowish, reddish, or grey in colour, and often with contorted bedding. Ripple-mark is sometimes present, approaching in type the "cauda galli" markings so often met with in the Carboniferous. Typical "cauda galli" markings occur in the Old Red Sandstone of Ben Griam Beg. Fragmentary plant remains are not uncommon. There are also little rounded bodies with a nucleus of marcasite, which weather

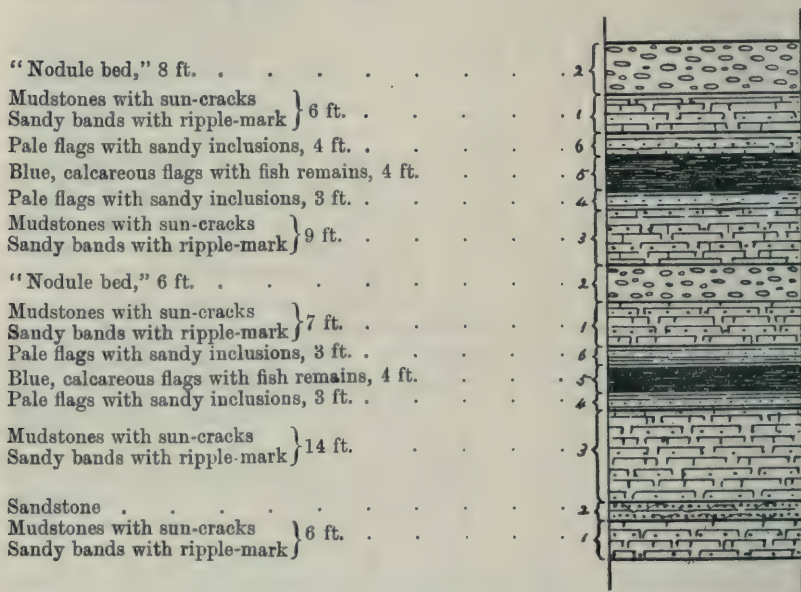


FIG. 20.—Vertical Section of part of the Mey Beds, to illustrate the type of Sedimentation.

out, and where they are numerous produce surfaces which might be thought to be due to rain-pitting.

The place of the sandstones in the sequence is often wholly or in part taken up by curious "nodule beds" (Plate VI., 1) which consist of crumpled layers of sandstone or more or less angular or rounded lumps of sandstone in a greenish, sandy mudstone matrix.

The beds suggest a breccia, but no foreign stones have been detected. The sandstone lumps are the same material as the sandstone bands in the group, and indeed these nodule beds may be traced laterally to pass into sandstone bands. There is often an indication that movements have occurred along certain planes almost parallel with the bedding, which suggests that the beds may have been formed as "crush breccias." This, however, cannot be the explanation, as these nodule beds recur again and again at the sandstone horizons in the sequence. Examination

* *Op. cit.*

of these curious beds points to some form of earth creep or landslide as the most plausible explanation.* The horizon of the "nodule beds" invariably follows beds with ripple-mark and sun-cracks. Such areas of creep might have surrounded depressions on the lake floor which acted as water channels when the water retreated from the mud-flats. The creep would then be due to re-wetting after shrinking from drying on a very slight incline. The so-called "hog-wallows"† in North America are produced through expansion by re-wetting of mud-flats which have shrunk and cracked in drying. The cracks become filled up by flakes of dried mud preventing lateral re-expansion of the mud on wetting, and the surface therefore bulges and becomes uneven.

A coast section of the Mey Beds about a mile east of Thurso shows the sequence illustrated in Fig. 20.

The John o' Groat's Sandstones.

The passage from the Thurso Flagstones into the John o' Groat's Sandstones is rarely exposed owing to faulting. At Freswick the junction is abrupt and suggests unconformity. There are a few thin bands of flagstone with fish remains peculiar to the John o' Groat's Sandstone, but otherwise the lithological change is complete and introduces the type of sedimentation of the Upper Old Red Sandstone. The sandstones are mostly yellow in the lower part and bright brick-red in the higher part of the sequence. They are often somewhat calcareous, and weather in a honeycombed manner, but are never cemented like the fine-grained sandstones of the Flagstone Group. They are friable, sometimes gritty, and very false-bedded. Small clay galls like fragments of flagstone are frequently seen. The bedding is often so contorted that it suggests the accumulation and erosion by wind or strong currents of flowing water.

SUMMARY OF EVIDENCE AS TO THE CLIMATIC AND OTHER CONDITIONS OF DEPOSIT.

The chief lithological peculiarities of the Caithness Flagstone Series may be summed up as follows :—

1. The prevalence of a red colour in the uppermost and lowermost groups and its almost complete absence from the rocks of the Flagstone Group proper.
2. The fresh condition of the fragments in the coarse arkoses and breccias, and the small amount of attrition, rolling and sorting in the conglomerates.
3. The abundance of organic matter in the rocks of the Flagstone Group proper coupled with a complete absence of coals or of the segregation of iron in the form of ironstones.
4. The abundance of lime in absence of fossils of lime-secreting organisms.
5. The uniformly fine-grained nature of the flagstone deposits and the mixed nature of the materials which form them.‡
6. The presence of a sedimentary rhythm of a peculiar nature in the rocks of the Flagstone Group proper.

* Dr. Flett informs us that beds very like these are met with in Bressay in Shetland.

† Hilgard, "Soils in the Humid and Arid Regions," 1911, p. 114.

‡ See Flett, "The Old Red Sandstone of the Orkneys," *Trans. Roy. Soc. Edin.*, vol. xxxix., 1898, p. 407.

Without attempting to discuss at length the theories on the production of red residual deposits and their relations to climate and vegetation,* it may be said that the chief factors in their formation are somewhat as follows :—

1. The exposure at the surface and chemical decay of rocks in which iron-bearing minerals are not only abundant but widely disseminated—particularly iron-bearing crystalline rocks, intrusives, volcanics, and gneisses.
2. The presence of vegetation to supply the soluble humus derivatives which are the chief source of rock decay.
3. A climate which is not so dry as to completely suppress vegetation, and if very humid, sufficiently warm to prevent souring of the soil and acid humus accumulation in places that are not swamps.
4. A rapid decay of dead vegetation in areas that are not swamps, and a permeation of the rocks by soluble humus derivatives in the presence of sufficient oxygen to allow of the oxidation of the iron compounds *in situ*.

The climate must be warm enough to prevent widespread humus accumulation, and wet enough to induce chemical decay of rocks. These conditions are best developed in tropical rain-forest, and are hindered by increasing cold or drought.

Cold humid conditions prevent decay of vegetation, and humus accumulates as acid peat, which covers the surface with a blanket impermeable in its lower layers. When waters derived from acid peat reach the rocks beneath, they reduce the iron compounds and render the iron soluble, and from their superior affinity for free or combined oxygen, hinder its local re-oxidation and precipitation. The rocks are therefore leached to a dull white, and the iron is carried away in the surface waters and accumulates by oxidation and precipitation elsewhere as definite layers and concretions of oxides and carbonates, which eventually form ironstones.

With great aridity or very low temperatures, plant growth and decay may be entirely arrested, but in a sufficiently warm climate slow, superficial decay and oxidation of the iron-bearing minerals will continue in positions retentive of moisture.

The formation of great masses of conglomerates of well-rounded fragments of crystalline rocks, like those of the Lower Old Red Sandstone, proves a period of upheaval and exposure of crystalline rocks to the forces of erosion. The contemporaneous outpouring of volcanic rocks in Lower Old Red Sandstone times, and their subsequent erosion would afford a further source for the supply of red sediments. That the climate of the Lower Old Red Sandstone times was sufficiently humid to lead to intense erosion and rounding of the fragments of hard crystalline rocks by stream action has been fairly established.†

The red colour of the rocks and the predominantly decomposed state of the feldspars of the Caledonian deposits therefore point to a climate which was not only humid but warm. We may infer from

* See I. C. Russell, "Subaerial Decay of Rocks," *U.S. Geol. Surv. Bulletin* 52, p. 535; Alexis Julien, "On the Geological Action of the Humus Acids," *Proc. Amer. Assoc. Adv. Science*, 1879, p. 311.

† Robert Campbell, "The Geology of South-Eastern Kincardineshire," *Trans. Roy. Soc. Edin.*, vol. xlviii., 1913, p. 954.

the absence of Caledonian deposits in Caithness that the area was undergoing erosion during the period of their formation.

When we turn to the lower barren red deposits of the Caithness sequence, we no longer find massive conglomerates of well-rounded boulders. The mudstones and arkoses are still red like those of the Caledonian, but the coarser deposits are of less extent and different in nature. The breccias consist of very angular and fresh fragments, and the conglomerates are full of fragile plate-like pieces of schist and subangular boulders, suggesting that transport by water had ceased to be so marked a feature. From torrential stream erosion and accumulation in the Caledonian, we pass to a phase of predominantly passive degradation in the Orcadian. The geography of Caledonian times must indeed have changed profoundly before deposits began to form in Lake Orcadie. A deeply dissected mountain scenery, with rapidly eroding watercourses, had been replaced by shallow continental basins from which peaks of the buried crystalline rocks protruded here and there. The mountainous regions, where atmospheric precipitation and stream erosion were concentrated, had retreated to a distance from Lake Orcadie, but probably still formed the chief source of its waters. The red colour of the mudstones shows that the climate remained warm, but the fresh and angular fragments of crystalline rocks in the breccias and arkoses suggest a change to more arid conditions. From widespread torrential accumulation along the base of a mountainous country with a high rainfall, the scene is shifted to plains where local erosion was mechanical and unaccompanied by decay. Red impalpable muds, the finest siftings from the products of chemical decay of crystalline rocks, still found their way into the region, perhaps transported by wind and ephemeral streams.

With the advent of flagstone formation the red colour disappears from the rocks. They become uniformly fine-grained, and large quantities of lime and organic matter become a conspicuous feature of the deposits. A peculiar rhythm in the sedimentation and the remains of an aquatic fauna are first encountered.

The absence of a red colour in rocks having much iron and organic matter is known to be due to the state of reduction of the iron compounds. Red soils are comparatively poor in humus, and red rocks are poor in fossil plant-remains or carbonaceous compounds.

Goodchild considered the absence of a red colour in the Caithness flagstones as due to the excess of organic matter, and it is undoubtedly true that as the organic matter increases in the flagstones the red colour gives place to shades of green and blue, and finally to grey and black. The iron is reduced to ferroso-ferric and ferrous compounds, and is often in the form of pyrites.

The appearance of so much organic matter is not to be accounted for by a change to a cold humid climate, since red rocks reappear at several horizons in the middle of the flagstone sequence, and may have been forming in the neighbourhood of Lake Orcadie throughout the period of deposition of the flagstones. Though it is probable that a wetter climate supervened, the disappearance of the red colour in the rocks can be explained as the direct outcome of the change in the conditions of sedimentation which introduced organic matter into the deposits through a constantly water-logged or subaqueous

condition of the surface. Under a cold and humid climate the accumulation of organic matter would have been general, and we should have expected at least some slight development of coals and ironstones.

Lime is distributed through the Caithness Flagstone series in a way that contrasts strongly with other geological formations, having such diverse lithological composition. Nearly all the rocks, from breccias to calcareous flagstones, contain lime, but the amount of lime generally increases with that of the organic matter in a way peculiar to the strata. The sudden appearance of highly calcareous and organic deposits seems to mark a change in the conditions of deposit from those of an ephemeral to those of a permanent drainage system. Within the range of the former the decay of vegetation would be rapid, preventing an accumulation of humus, while within the sphere of the latter, lime, accumulated through precipitation and some form of vegetation, was abundant, and from its subaqueous accumulation was preserved from complete destruction.

Organic matter is peculiarly abundant in the flagstones, considering the scarcity of well-preserved plant remains and the rarity of recognisable plant tissues under the microscope. On dissolving the black calcareous flags in acid, the organic matter is separated as a brown flocculent precipitate, for the most part structureless, and perhaps related to bitumen.

With few exceptions, the organic matter is most abundant in the most calcareous strata of any sequence, and must have chiefly accumulated where the conditions were favourable for the precipitation of lime on the lake bottom. If the organic matter were chiefly derived from vascular plants growing in shallow water or swept down the streams, or from finely-divided humus suspended in the incoming waters, we should have expected to find thin coal layers or more abundant plant debris in the terrigenous deposits. Plant remains are scarce even in strata black with organic matter.

The chief source of the organic matter may have been confined to the water of the lake and derived from a microphytic algal plankton, such as has been suggested for the origin of certain cannel coals and shales rich in volatile hydrocarbons.

Fossil fish are sufficiently abundant in the Caithness flagstones to show that the waters of Lake Orcadie were well-stocked with forms of life necessary for their food. An algal plankton would form a basis of this food supply.

The extensive flagstone surfaces covered with perfect fish remains, suggest that the fish periodically came to an untimely end through some rapid change producing unfavourable surroundings. The layers with fossil fish are the most calcareous strata formed at places farthest removed from the spread of incoming sediment. The fish appear to have retreated with the waters, and their accumulation as fossils may have depended on parts of the drainage system becoming isolated as lagoons, where the fish were eventually trapped, suffocated, and entombed by the encroachment of alluvial sediments. The abundance of lime is as striking a feature of the Caithness flagstones as their organic matter, but the lime must of necessity have been brought into the lake in solution or suspension.

Microscopic sections of the limestones show the lime as partly

amorphous and partly crystalline calcite, but no organic cause for the segregation of lime has been detected. Lime is found in practically all the strata of Lake Orcadie. It was evidently precipitated all over the lake-bed, and its accumulation to form limestones depended chiefly on the local absence of other sediments.

Goodchild * believed that the carbonate of lime and bitumen in the flagstones were due to a chemical reaction between the organic debris and sulphate of lime in solution in the waters of the lake.

It is probable, however, that the bulk of the lime entered Lake Orcadie as carbonate. Carbonate of lime is present in the red deposits where organic matter is wanting, and the tufa deposits of Red Point, etc., show that carbonate of lime was at least locally abundant in the waters of the drainage system. The precipitation of lime from the waters of the lake must have depended either on its absolute excess or on the lake waters being subject to evaporation and concentration. The latter, however, must have been of quite secondary importance, since even gypsum deposits are completely wanting.

Fragments of Cambrian limestone have been detected in the Middle Old Red Sandstone of Ross-shire and Orkney, but we have nothing to guide us as to the extent to which the Cambrian limestones were then undergoing denudation. A likely source of the lime lies in the subaerial deposits formed under conditions of ephemeral drainage. From the excessively fine-grained nature of the flagstones, their enormous thickness, and their method of accumulation by crustal warping in a continental basin, it is obvious that the bulk of the sediments of Lake Orcadie must have been derived by transport of marginal deposits towards the centre of the basin. Lime temporarily locked up in the marginal deposits would gradually find its way into the waters of the lake.

The crystalline gneisses of our Northern Highlands could not, however, supply the enormous amount of lime locked up in the Caithness flagstones, unless an arid cycle causing the accumulation of lime in ephemeral deposits had intervened. Under a perpetually humid climate, nearly all the lime would have reached the sea, and could only have been retained through some organic cause of accumulation. Lime accumulates in the sediments of arid regions, but the drainage rarely contains much carbonic acid in solution, and lime in solution is small in quantity and takes the form of sulphates.

Though not unknown in semi-arid regions, the subaerial tufa deposits in the basin of Lake Orcadie might be considered as indicating a change to a somewhat wetter climate, with the advent of the flagstones. The great stores of carbonate of lime locked up in the subaerial deposits of early Orcadian times, would be rendered more quickly available under such conditions. A semi-arid climate is indeed the driest one consistent with the presence of large sheets of shallow water without any deposition of gypsum or other saline deposits. The drainage system supplying Lake Orcadie must further have had its source in regions of considerable rainfall.

The probable sequence of events leading to the accumulation of the Caithness Flagstone series, may therefore be summed up as follows.

1. A period of aridity followed the Caledonian Old Red Sand-

* *Loc. cit.*

stone, during which the breccias and fine-grained red sediments of the Barren Group accumulated.

2. Following this there was probably a slow change to somewhat wetter conditions, and the lacustrine deposits of Lake Orcadie gradually invaded the region. Red arkoses and mudstones are replaced by regular rhythmic sequences of very fine grey sandstones, greenish mudstones with sun-cracks, and dark blue or black calcareous slaty beds and limestones. The presence of fish remains in the limestones shows that the waters had become sufficiently constant to support an aquatic flora and fauna, and the regular sedimentary rhythm demonstrates equally clearly how the waters of the lake periodically advanced and retreated. The limestones were evidently formed in areas remoter from the influx of sediment, or in lagoons shut off from this supply. The sandy beds prove an encroachment of the delta deposits over these areas, while the sun-cracked mudstones were formed in areas of the flood-plain subject to seasonal alternate inundations and drought. As warping and sedimentation proceeded, the flood plains were again covered by the waters of the lake, and the formation of limestones again commenced. We find, therefore, a sequence in which limestones are followed by sandy beds with signs of current bedding, and these in turn by sun-cracked mudstones.

The relations between crustal warping and sedimentation, which led to these changes of water-level, were sometimes of such extent as to bring about prolonged extensive retreats of the lake waters, and the Red Beds of Brough and Lybster probably mark an advance of marginal deposits over areas previously covered by the waters of the lake.

3. Further crustal warping led to a wider extension of the lake with a great increase in the amount of muddy sediment, but changes of water-level of seasonal origin became less marked, and the winds blowing over the surface of the waters have left abundant traces in well-defined, broad ripple-marks, repeated with a constant north-west to south-east orientation over a great thickness of strata. With this there is a greater mixing of the bottom deposits, and the clay, sand, micas, organic detritus, and precipitated lime are combined to form the dark flagstones of the Wick Group.

The depth of water from seasonal causes appears to have been less variable than in the earlier beds, and the flood plains were less often exposed to the air.

4. The Papigoe Beds mark the beginning of a change in the type of sedimentation, owing to a great extension of the flood-plain of Lake Orcadie. Wide areas were longer free from land-derived sediment, and precipitated lime accumulated to form the Papigoe limestones. The delta and flood-plain deposits, which encroached on the limy sediments, were chiefly pale calcareous muds, and were frequently exposed to the air with the formation of sun-cracks. The Achanarras and Niantd Limestone horizon, which lies at the boundary of the Passage Beds and the Thurso Flagstones, marks a great addition to the fish fauna. The number of species which, so far as Caithness is concerned, are confined to this horizon, forms a peculiarity for which at present no entirely satisfactory explanation is forthcoming. As to the sudden increase in the fauna, it may be that extension of Lake Orcadie at the Achanarras period was so great as to cause a

breaking down of some geographical barrier which had separated faunas previously confined to different basins. Lake Chad is believed to form but one of a chain of lakes which formerly connected the river basins of the Nile and the Niger, since its fish fauna shows strong affinities with those of both river basins, while also having a few peculiar species of its own. Lake Orcadie in a similar manner may have acquired connection with more than one river system, and additions to its fauna would result from changes in its extent and migrations due to crustal warping. It is at least clear that the Achanarras fish fauna could not have evolved from the fish fauna as yet discovered in the beds below.

5. The oncoming of the Thurso Flagstones marks an even greater extension of Lake Orcadie. Only the finest silts were now carried far and wide over the flood-plain, but the areas cut off from sedimentation were very limited. That the waters had become very shallow is shown by the excessive admixture of the terrigenous silts, organic debris, and calcareous precipitates. Ripple-marked surfaces show much narrower ridges and furrows than in the Wick Flagstone strata, or are absent. The constant orientation seen in the ripple-mark on the latter beds is also wanting. It is in association with sun-cracked beds in the Thurso Flagstone Group that we first find possible indications of "runnels" that traversed the mud-flats or low-water deltas, as noted in the descriptions of the Ackergill and Mey Beds. In these we perhaps have the beginnings of the great change which culminated in the formation of the John o' Groat's Sandstones. The latter appear to have resulted from crustal disturbances which eventually led to the migration of the lake deposits beyond the area of rocks to which we now have access. Lake Orcadie may thus be pictured as one of several sheets of very shallow water varying in number, position, and communication with one another, with a permanent drainage system depending on the direction of crustal warping and the age of the accumulations in the basin.

With semi-arid surroundings and a warm climate, its waters supported abundant plant and animal life, and were subject to extensive advances and retreats from variations in the water-level due to silting and periodic seasonal changes, or from bodily migrations induced by warping of the basin of deposit. At one time extensive shallow lakes, at another endless mud-flats and stagnant lagoons. At first, semi-desert shallow valleys and half-buried mountain peaks with fans and flood-plains of ephemeral streams; later, extensive lakes and alluvial deposits; and at last, a wind-swept plain of sand and wandering water courses.

C. B. C.

CHAPTER X.

THE UPPER OLD RED SANDSTONE.

THE pink and yellow sandstones of Dunnet Head have long been regarded as of Upper Old Red Sandstone age. This correlation was suggested by Sedgwick and Murchison in their paper communicated to the Geological Society in 1828.* No palæontological evidence, however, has yet been obtained to prove the horizon of these strata. But there can be little doubt that they are a continuation southwards of the yellow sandstones of Hoy, which, as Sir A. Geikie has shown, rest unconformably on the flagstones of that island, yielding fish remains belonging to the Caithness Flagstone series.†

Dunnet Head forms the most northerly promontory of Caithness and measures about three and a half miles in length and about two and a half in breadth. The promontory is almost entirely made up of pink and yellow sandstones, shales, marls, and mudstones, which give rise to high precipitous cliffs on the three sides facing the sea. On the landward side these strata are bounded on the east by the Brough fault, along the line of which the flagstones of Middle Old Red Sandstone age have been thrust across the edges of the sandstone (Fig. 21). This dislocation was clearly recognised by Sir A. Geikie, and figured by him as a normal fault.‡ It was noted by Sedgwick and Murchison,§ but in his later memoir on "The Succession of the Older Rocks in the Northern Highlands," Murchison referred to the locality as one where the flagstones passed upwards into the yellow sandstones.||

The strata of the promontory form the southern end of an elongated shallow basin with a nearly north and south axis and a northerly pitch. In consequence of this structure, the lowest visible beds are exposed in the south-east angle of Dunnet Bay, where they consist of very false-bedded yellow sandstones dipping mostly northwards at angles varying from 10° to 15° (Fig. 21). The curved laminae due to false-bedding are well displayed on the horizontally planed surfaces between tide marks. Galls of reddish clay or shale are also involved in the sandstone as if they had been derived by the wind from dried-up mud-pools and borne along with the drifting sand now consolidated into stone. Contemporaneous erosion must also have taken place, for, within a distance of a few yards, more than one instance of the erosion of the more evenly bedded sandstones, now filled in with the curved false-bedded material, may be seen. Along

* *Trans. Geol. Soc.*, Second Series, vol. iii., 1829, p. 125.

† *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 398.

‡ *Op. cit.* p. 398.

§ *Op. cit.* p. 134.

|| *Quart. Journ. Geol. Soc.*, vol. xv., 1859, p. 409.

some of the layers calcareous concretions are to be found, evidently marking periods of dessication during the accumulation of these rocks. Sun-cracks are of common occurrence in the more shaly beds. Obscure organic remains resembling roots of lepidodendroid plants were observed among the blocks of sandstone excavated near the bridge that crosses the streamlet draining St. John's Loch.

Northwards from the head of Dunnet Bay the trend of the coast-line is north-west for about two miles. The dip of the false-bedded yellow sandstones forming the cliffs is towards the north at angles varying from 5° to 10° . Inland the strata are mostly concealed under boulder-clay, but a few exposures occur at various localities, as, for example, along a ridge extending from Dwarwick Head to beyond West Dunnet, where the yellow and pink sandstone has been quarried for building stone and other purposes. Again a prominent belt of this type of rock occurs on each side of the Loch of Bushta, and forms the western cliff as far as the point where the coast line bends to the north. Beyond these exposures in a northerly direction, the rocky ridges within this belt subside under drift and peat, but they reappear near Courtfall, where sandstones are extensively quarried, being conveniently near the main road. To the north-east of this road the rocks pass under drift and peat, but once more come to the surface in the eastern cliffs between Brough and Outer Sinni Goe. Here they are under the influence of the Brough fault, for in the bay at Brough they are thrown into sharp overfolds and much shattered, while in the sea-cliff they are inclined to the north-west. Near Brough the angle of dip is about 25° , but decreases northwards to 10° at Sinni Goe (Fig. 21).

North of the belt of strata just described, the western shore trends northwards by the Red Goe and Ashy Goe for about a mile and a half, where the sandstones are less markedly false-bedded and often occur in bands a foot or two in thickness, separated by layers of grey or greenish clays or mudstones. Proceeding inland from the cliffs, we find that these strata are buried under superficial deposits, but farther inland they emerge and give rise to a succession of sub-parallel bare ridges with intervening hollows partly filled with peat and drift, and partly occupied by lochans, some of which are fringed with sandstone and are probably rock-basins. This type of sedimentation is again visible on the east coast where the beds dip to the north-west at angles varying from 10° to 15° as if they were still under the influence of the Brough fault.

In the triangular area nearest Dunnet Head (Sheet 117), the strata consist of friable yellow and variegated sandstones dipping at very low angles. On the west side the inclination is towards the east-north-east; in the centre, towards the north; and on the east side towards the west or south of west. Hence the basin-shaped arrangement of the strata is here quite apparent. Owing to this structure the highest beds are not found on the most northerly point of the promontory where the lighthouse is built at Easter Head, but at a distance of about half a mile to the west-south-west of that point.

The rocks of the headland are traversed by only a few faults which have a slight downthrow. They generally give rise to clefts and sometimes to "goes" or inlets indenting the cliffs, but many

of these also occur along joint planes or along hollows due to the weathering out of thin dykes of monchiquite.

Allowing for slight repetition by faulting, we estimate the thickness of Upper Old Red Sandstone exposed on this headland at about 1800 or 2000 feet.

B. N. P.

CHAPTER XI.

IGNEOUS ROCKS.

VOLCANIC VENT NEAR DUNNET HEAD.

THE Burn of Sinnigoe, which falls into the sea a little to the north of the village of Brough, traverses for a distance of about 300 yds. a mass of mixed sedimentary and volcanic material that in all probability fills a volcanic orifice piercing strata supposed to be of Upper Old Red Sandstone age (Fig. 21). The material consists of a rusty sandy paste in which are set fragments of sandstone with a considerable admixture of slaggy basic igneous rocks too much decomposed for exact determination. The agglomerate is also exposed on the steep slopes on the north-east side of the stream, while towards the south-west it is covered by a high bank of boulder-clay.

The junction of this material with the surrounding sandstones is nowhere visible, but towards the foot of the burn the two sets of rocks come within a few feet of each other, the actual contact being concealed beneath huge blocks of sandstone thrown up by the sea during storms (Fig. 22). The sandstones where exposed on each side of the outlet of the stream do not seem to be hardened or much disturbed. At the north-west end of the mass the strata near the agglomerate appear to be hardened and show some signs of disturbance, though retaining their normal direction of dip towards the north-west at low angles.

If the agglomerate were interbedded with the sandstones it ought to appear on the cliffs, which are here about 100 ft. high. But no trace of it has there been detected. Its mode of occurrence rather suggests that it fills a vent which was drilled through these rocks while they were less coherent than at present. A suggestion was made * that this orifice may have been connected with the volcanic phase that began in Scotland in Upper Old Red Sandstone time. The evidence obtained in Hoy (Orkney), where volcanic necks pierce the Middle Old Red Sandstone at the north end of that island, and where a volcanic platform is interbedded with the yellow and red sandstones that rest unconformably on the flagstones, strengthens this conjecture.†

B. N. P.

VOLCANIC VENT AT DUNCANSBY.

At the Ness of Duncansby there are two small areas of igneous rock and agglomerate tuff. They are bounded by the rocks of the

* "Summary of Progress for 1905," *Mem. Geol. Surv.*, pp. 114-115.

† Sir A. Geikie, *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, pp. 406 and 411.

E.

THE BROUGH

DUNNET HEAD

W.N.W.

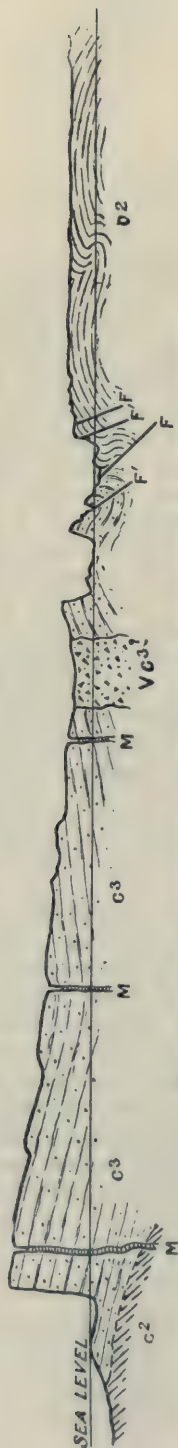


FIG. 21.—Sketch Section across Dunnet Head from shore north of Dunnet to Ham.

John o' Groats' Sandstone group, with which they form rocky reefs between tide marks. Both of these masses of agglomerate pass under the beach and blown sand on their landward margin, and it is therefore impossible to say if they form one or two separate foci of eruption.

The size, shape, and relations of these areas of agglomerate are seen in the annexed plan (Fig. 23). C. B. C.

Petrography.

The rocks which fill the neck at Duncansby are nepheline-basalt tuff with dykes of nepheline-basalt. The tuff contains basaltic bombs of all sizes up to several feet in diameter and pieces of sandstone and other foreign or accidental materials, together with large broken crystals of augite and biotite which have crystallised from the volcanic magma and are consequently of cognate or authigenic origin.

The tuff itself is much decomposed. Sections of some of the bombs show that they are fine-grained, very basic rocks with small phenocrysts of augite and olivine (the latter rarely fresh) in a groundmass rich in small prisms of augite embedded in analcite, calcite and other secondary products. Like the nepheline-basalt of the necks these bombs contain many angular fragments of sandstone, and in microscopic section all stages of absorption of the sedimentary materials by the volcanic magma may be traced.

The intrusive masses in the tuff of the necks are dark fine-grained rocks exactly like the bombs, and are also crowded with xenoliths of many kinds. The western neck consists almost entirely of material of this character and is so full of fragments of sandstone that it looks like a fragmental rock. In the eastern neck there is more tuff and less basalt, but a fairly large intrusive mass occurs on the west side.* The bombs are finer-grained and more decomposed than the intrusive mass; they are also much more vesicular, but a comparison of the two kinds of rock shows that they are derived from the same source, and

* Sir Archibald Geikie, "On the Old Red Sandstone of Western Europe," *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 406.

the intrusive basalt represents merely the last part of the volcanic magma to well up into its present position.

In microscopic sections both the bombs and the intrusive basalt show phenocrysts of olivine and augite. Only occasionally is the olivine fresh enough to give its characteristic polarisation tints; for the most part it is replaced by serpentine or carbonates. The augite is always fresh and is of that purplish

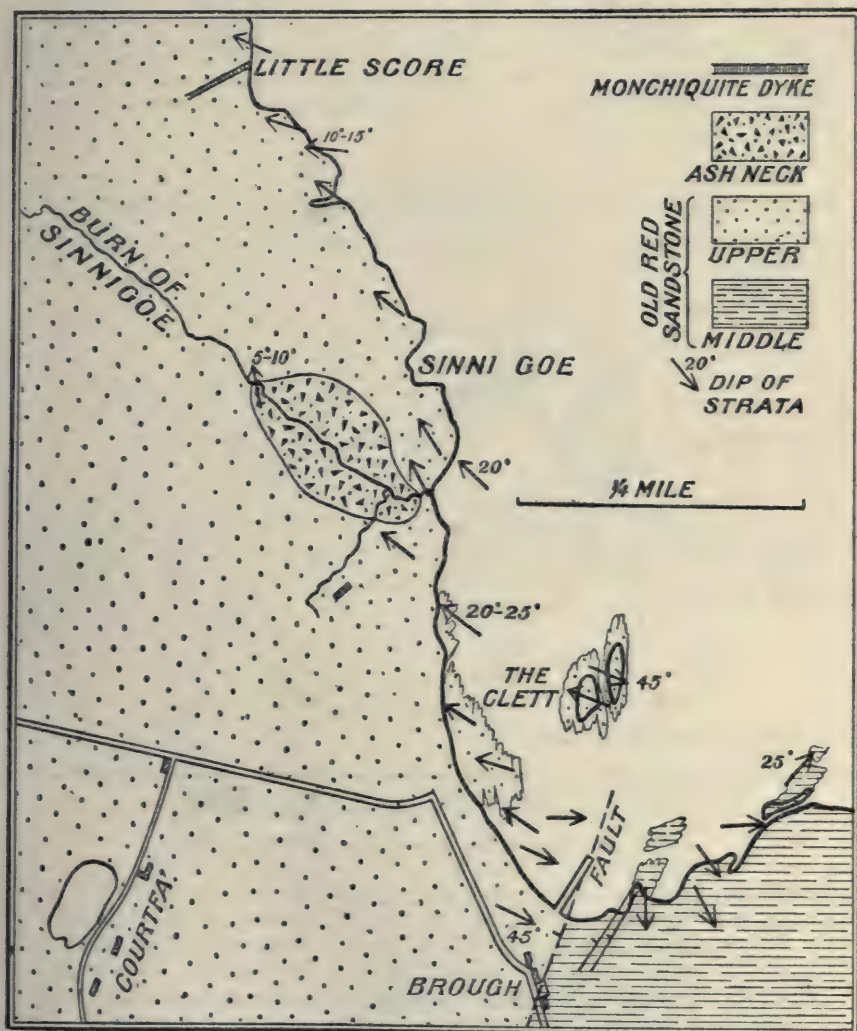


FIG. 22.—Map showing the position of the Volcanic Neck at Dunnet Head.

variety, with zonal and hour-glass structures and marked dispersion, which is usually described as titaniferous. Its crystals are sometimes twinned either on the front face or one of the pyramids. The groundmass is full of lesser prisms of the same kind of augite and occasionally contains a small amount of clear brown glass. A deep-brown biotite is present also as minute irregular scales. There is no felspar in the rock as a rule, and the little augites lie in a turbid matrix of decomposed glass with calcite, iron oxides, and carbonates.

More than a dozen sections of the basalt were prepared, and two of them show a mineral with the properties of nepheline. It is colourless and has a refractive

index slightly below that of the balsam in which the sections are mounted (1.544). The polarisation colours are dark grey, and the sections which have strongest double refraction often exhibit also a single cleavage, fairly well marked. Referred to this cleavage they have a straight extinction and negative optical sign. By immersion for thirty minutes in strong cold hydrochloric acid this mineral gelatinises, leaving a clear silica-jelly which stains with malachite green. These tests leave no room for doubt that the mineral is nepheline. It has been found only in those parts of the intrusive rock which have the most coarsely crystalline groundmass; where the rocks are finer-grained the matrix has apparently been glassy. The nepheline is mixed with calcite, analcite, and other secondary products, and does not show any crystalline outlines. The most extraordinary thing about this rock is that the nepheline is found in specimens which are so much decomposed that the olivine is altogether replaced by carbonates and serpentine.

The cognate xenocrysts in the tuff are olivine, augite, and biotite. The olivine is never fresh, but is replaced by carbonates and serpentine.

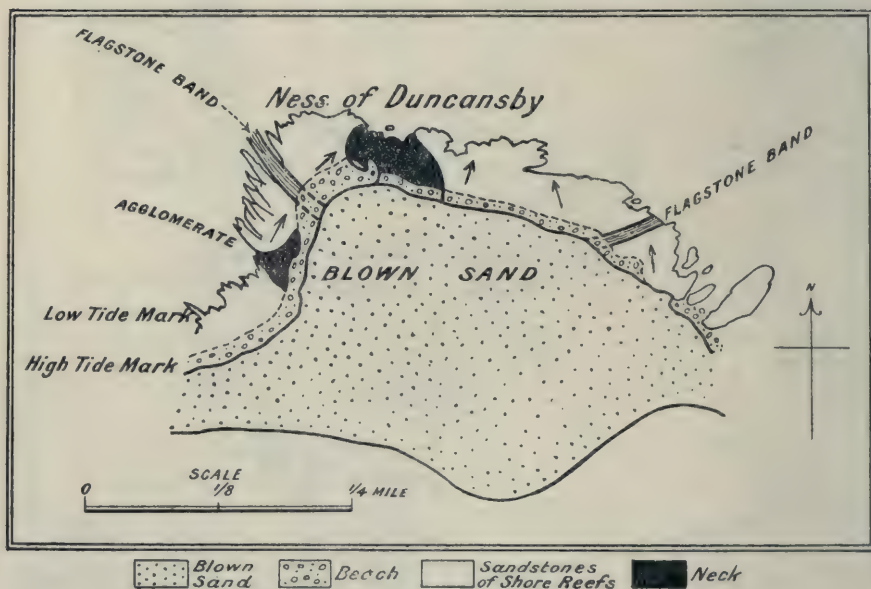


FIG. 23.—Map of the Volcanic Neck at Duncansby.

There are, however, small granular crystalline masses consisting of augite and pseudomorphs after olivine, which are so characteristic in their structure and microscopic characters that their origin cannot be questioned. Some of these "bombs" consisted practically entirely of olivine with a little magnetite and another mineral which is black in reflected light, but in very thin section is slightly transparent with a dark green colour. Probably this last is one of the chrome-spinels. The amount of augite in the olivine bombs varies greatly; in some the pyroxene forms more than one-half, while in others it is very scanty. It is always of a clear, rather pale green colour, not zonal, and remarkably free from inclusions. Occasionally a single well-developed cleavage gives the mineral a resemblance to diallage. None of the components of these "bombs" shows crystalline form. When the olivine is entirely changed to carbonates the augite usually has a narrow border infiltrated with secondary

products along numerous cleavage cracks, but the central parts of the crystals may be quite homogeneous and unflawed.

These olivine bombs, both in structure and composition, are exactly the same as those found in many Tertiary basalts. Aggregates of this kind are extremely rare in the igneous rocks of Britain, but a few have been met with in the basalts of East Lothian * and of Bathgate.†

Lumps of augite are much more common than olivine "bombs" in the tuff; they are frequently 2 or 3 ins., and sometimes as much as 6 ins. in diameter. They are all fragments of crystals, and, when struck with the hammer, show the prismatic cleavage of pyroxene very clearly. Heddle ‡ has described them as "augitic glass," but this is a misnomer, as none of them has been fused, and they have the optical properties of augite. Their surfaces are rounded by corrosion or partial solution in the magma, but many of the fragments have broken along their cleavages and the faces are rough. Though black in the hand specimens the augite in section is transparent and pale green like that of the olivine bombs. It has an extinction angle about 44° and an axial angle of 110° , and is remarkably homogeneous and free from cleavage. The principal inclusions are octahedra and rounded grains of magnetite and dark green chrome-spinel. Lines of rounded or branching fluid cavities are also seen in the sections. The prismatic cleavage of pyroxene is well-marked in some crystals, and none of them has the lamellation of diallage. The chemical analysis of this augite, quoted below, was made by Heddle § on material supplied to him by Sir Archibald Geikie. It is believed that the monoclinic pyroxene of the olivine bombs which occur in the basalts of Germany is usually a "chrome-diopside," but, unfortunately, the amount of chromium in the augite from Duncansby is not known.

SiO ₂	..	..	..	..	46.076
Al ₂ O ₃	..	..	..	..	11.391
FeO	..	..	..	..	7.921
MnO	..	..	..	..	0.461
CaO	..	..	..	..	16.067
MgO	..	..	..	..	15.653
K ₂ O	..	..	..	..	0.818
Na ₂ O	..	..	..	..	1.058
H ₂ O	..	..	..	..	0.38
					99.825
Sp. gr.	..	..	..	..	3.36

The only other mineral of pyrogenic origin which is found in the tuff is black biotite, in large plates rounded by corrosion and often crumpled by movements. It is uniaxial and strongly pleochroic in colours ranging from pale yellow brown to dark brown. Biotite is distinctly scarce, but occurs both in the tuff and as rounded xenocrysts in the nepheline-basalt of the dykes. No bronzite or

* E. B. Bailey, in "The Geology of E. Lothian," *Mem. Geol. Surv.*, 1910, p. 107.

† J. D. Falconer, "On the Igneous Geology of the Bathgate and Linlithgow Hills," *Trans. Roy. Soc. Edin.*, vol. xlv., 1906, p. 134.

‡ M. F. Heddle, "Chapters on the Mineralogy of Scotland; Chapter IV.," *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 482; "Mineralogy of Scotland," vol. ii., 1901, p. 27.

§ *Loc. cit.*

enstatite, so common in the olivine bombs of the Continent * has been obtained at Duncansby. Brown hornblende also is absent, and there is neither felspar nor nepheline in the bombs which have been microscopically examined.

The closest parallel which Scotland furnishes to these crystalline minerals in the tuffs of Duncansby is the occurrence of augite in the volcanic necks at Elie in Fifeshire.† There also the rocks are of a limburgitic type, and it has now been ascertained that some of them contain nepheline in a fresh and recognisable condition. But at Elie the augite is accompanied by sanidine (soda-microcline) and hornblende, and all three minerals are found also in some of the limburgitic (or monchiquitic) dykes which cut the tuffs of the necks.

In both cases the minerals of the tuffs are of "cognate" derivation with the basaltic magma which fills the necks. They are "protogenic" minerals; that is to say, they represent the first crop of crystals, which formed under conditions which were not present during the later stages of consolidation. These conditions were probably great pressure, retention of moisture, and slow cooling, such as we may easily postulate for the period which preceded the uprising of the magma in the necks. The protogenic olivine and the later olivine are presumably alike, but the early augite is clear green and quite different from the purple zonal augite of the later stages of crystallisation. The green spinels also are not found in the nepheline-basalt. The abundant fluid cavities in the green augite are also very significant of the conditions of pressure under which these crystals formed, for they indicate a similarity to the minerals of the true plutonic or abyssal rocks.

Foreign Materials in the Tuff.

Among the rocks found as "xenoliths" in the tuff and basalt of the necks Sir Archibald Geikie ‡ has enumerated the following—red sandstone, flagstone, limestone, and gneiss. By far the commonest are red and yellow sandstones, like those of the John o' Groats' beds through which the neck has burst. Some of these blocks measure several feet in diameter, but most of them are less than 6 ins. The gneiss occurs only in small pieces, and there is a large number of rounded fragments of pink granite or aplite, rich in alkali felspar. Pinkish quartz-porphry also was found among the xenoliths which were sliced.

The larger lumps of sandstone are angular and have neither been much baked nor dissolved. The smaller pieces, on the contrary, have often an indurated or glazed appearance, and are rounded at their corners and edges by the solvent action of the magma. In the

* F. Zirkel, "Lehrbuch der Petrographie," Band ii., 1894, p. 931; "Ueber Urausscheidungen in Rheinischen Basalten," *Abh. Kön. Sächsischen Gesell. der Wissen.*, Band xxviii., 1903, p. 103.

† Sir Archibald Geikie, "On the Carboniferous Volcanic Rocks of the Basin of the Firth of Forth," *Trans. Roy. Soc. Edin.*, vol. xxix., 1880, p. 462; "Ancient Volcanoes of Great Britain," vol. ii., 1897, p. 79; "The Geology of Eastern Fife," *Mem. Geol. Surv.*, 1902, pp. 232 and 394.

‡ Sir Archibald Geikie, "On the Old Red Sandstone of Western Europe," *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 406.

hand-specimens many fragments no larger than an almond or a pea may be observed gradually losing their identity and merging with the black basaltic matrix which surrounds them.

In microscopic slides of the basalt separated crystals of quartz and felspar may often be seen. The quartz is invariably much corroded and is surrounded by broad or narrow zones containing small prismatic crystals of augite. Grains of felspar are almost as common as quartz; they are usually untwinned and belong presumably for the most part to orthoclase. The felspar is not surrounded by the resorption borders of augite like the quartz, though it is embayed and eroded by the solvent action of the magma. As felspar is much less frequent than quartz in the sandstones its abundance in isolated xenocrysts indicates that it was not so readily dissolved by the fluid basalt.

In many of the slides there are minute rounded ocellar spots, less than a millimetre in diameter. At their outer edges they contain much augite of greenish colour in small prisms which converge towards the centres of the spots. In the interior these augites are scanty and a clear or yellowish granular substance makes its appearance. The clear colourless material is sometimes felspar, as is evident from its optical properties and occasional simple twinning; the species of felspar was not ascertained, but small prisms rather irregular in shape may make up a crystalline aggregate, and at other times a single shapeless felspar crystal forms the whole centre of the spots. The formation of augite and felspar by the resorption of enclosures of quartz-felspathic rocks in basalt has been recorded by Lacroix,* and that this is their origin here is shown by the not infrequent presence of much-corroded residues of quartz and felspar in these ocelli. The new felspar can be distinguished from the foreign felspar by its perfect clearness and occasional traces of idiomorphism, the derived felspar being often cloudy with decomposition or with fluid enclosures. Mr. Harker † has described the crystallisation of brush-like growths of felspar around enclosed fragments of nepheline in the basalts of Skye, but the felspars in the ocelli of the Duncansby nepheline-basalt are usually prismatic.

When the centre of the spots is a turbid yellow substance this is apparently a devitrified glass, for though it is cryptocrystalline and shows aggregate polarisation between crossed nicols, it contains minute prisms of greenish augite, sometimes long, narrow and curved, similar to those found in many fused sediments. A good example of the production of glassy patches containing small crystals of augite from the resorption of quartz xenocrysts in basaltic rocks is furnished by the basalts of Elie and Largo ‡ but the phenomenon is a common one and needs no special comment.

Fragments of sandstone less than a millimetre in diameter sometimes have been much altered, and show many interesting changes. The xenoliths are permeated with carbonates, but this is probably secondary, for there is no special abundance of calc-silicate minerals. The quartz resists fusion, but the interstitial material is sometimes converted into a yellow granular substance like that found in the centres of the spots. It also contains small augite needles and prisms, and is never quite isotropic in polarised light. No cordierite has been seen in this glass, though its presence is to be expected since vitrified sandstones in contact with basaltic dykes contain that mineral in many parts of the West of Scotland, and Lacroix § has found it in enclosures of quartz-felspathic rocks in basalt. Around the quartz grains there are sometimes coronas of granular augite, recalling those which occur around the quartz xenocrysts in the basalt matrix. For

* A. Lacroix, "Les Enclaves des Roches Volcaniques," pl. i. figs. 9, 10, 11, 1893.

† A. Harker, "The Tertiary Igneous Rocks of Skye," *Mem. Geol. Surv.*, pl. xxiv. fig. 4, 1904.

‡ "The Geology of Eastern Fife," *Mem. Geol. Surv.*, 1902, p. 401.

§ *Loc. cit.*

a short distance about their edges (less than a millimetre in all cases) there is an interfusion of the substance of the xenoliths and the nepheline-basalt, but the glass in the centre has been produced by the fusion of the sandstone cement, not by invasion of the magma.

Xenoliths of another type occur in the nepheline-basalt. They are found in several of the slides, and are of angular shape and dark grey colour, not readily distinguished in the hand specimen from the basalt matrix, but not quite so dark as the latter, and rather more transparent in the microscopic sections. These fragments contain no residues of clastic quartz or felspar, and seem to be xenoliths of cognate rather than of accidental type. They are distinguished from the surrounding basalt by many features. They contain no olivine and no recognisable pseudomorphs after it. Augite occurs only in very small grains, not as phenocrysts; most of it takes the form of small elongated narrow prisms, which are not nearly so large as the pyroxene of the second generation in the groundmass of the basalt. Nepheline is present in great abundance, partly as irregular crystals, but also as well-shaped hexagonal prisms with flat terminations; the mineral gelatinises readily and can be stained. The other elements of these xenoliths are a turbid brownish substance, which is either analcite or glass, and is practically isotropic, and abundant iron oxides, carbonates and other secondary minerals. The outer zones of the xenoliths are full of fine augite, and are very dense and compact, while the centres are more coarsely crystalline. Felspar occurs in small quantity as long, branched fibres which are best seen when the carbonates and nepheline have been removed by acids.

J. S. F.

DYKES.

At least five thin dykes of basic rocks have been observed to cut the sandstones of Dunnet Head in a direction a little north of east and south of west. Owing to extreme decomposition, they are now for the most part represented by an ochreous clay with veins of limonite, which is readily removed by aqueous action, thus giving rise to clefts. The most accessible one can be traced for about 200 yds. across the rocky platform, exposed at low tide beneath the cliff near the south-east angle of Dunnet Bay. It is about 3 ft. wide, and though not so much decomposed as the others, it is too decayed for accurate determination. There can be little doubt, however, that it is an extension in an east-north-east direction of one of the dykes on the opposite shore of the bay west from Castlehill, which there intersect the flagstones.

Two decomposing dykes have determined the inlet known as Chapel Goe, east from the Loch of Bushta. Still farther north, another forms the Red Goe, and a fifth gives rise to the hollow named the Long Byre about $\frac{2}{3}$ of a mile west-south-west from the lighthouse.

The feature of special interest connected with these dykes is that they here cut strata, believed to be of Upper Old Red Sandstone age, and must therefore be of later date (Fig. 21).

B. N. P.

Two dykes only, both having a north-east trend, have been met with farther south in Caithness. One is in a quarry on the north of the road between Barrock Mill and Reaster House. The second

is in a quarry in the field surrounding Toftcarl in the Thrumster district.

C. B. C.

Petrography.

The dykes which occur in a group on the shore about half a mile to the north-west of Castletown are all monchiquites. They are dark, fine-grained rocks with small phenocrysts of olivine which have been replaced by serpentine. Some of them weather with a tubercular or nodular surface, the nodules being less than half an inch in diameter; a similar mode of weathering was observed by Dr. Peach * in a camptonite in the island of Scarba, Argyllshire. Small vesicles in these dykes are occupied by carbonates and black bitumen. The dyke which is exposed in the flag quarries at Castletown is also a monchiquite.

In section these monchiquites show, in addition to the small porphyritic olivines, only a fine groundmass consisting of idiomorphic purple augite, a little reddish-brown biotite, and a turbid interstitial material. The little augites have rather long and narrow forms and are seldom twinned. The biotite is less idiomorphic than the augite, and the interstitial substance consists of calcite, chlorite, analcite and other decomposition products. No glassy material and no nepheline were observed in satisfactory preservation in the slides. In this rock many rounded ocelli occur belonging to the type commonly associated with camptonites and monchiquites. They are small, being usually about a millimetre in diameter, and are often very numerous, forming a considerable part of the rock. In them brown hornblende occurs in long prisms with cross sections of characteristic shape, together with feathery or brush-like feldspars and cloudy analcite. The radiate arrangement of the components is usually conspicuous, and in the centre of the ocellus there is often a cavity which has been filled up with carbonates or analcite.

Near Lochside, a mile south-east of Reaster House, a monchiquite dyke occurs, very like those of Castletown, but containing fresh olivine and porphyritic purple augite, sometimes forming glomero-porphyritic groups. Rather large patches of analcite are visible in the slides of this rock, but the ocellar structure is not so well-developed as in the Castletown dykes. Biotite occurs in small amount both in the matrix and in the ocelli, but hornblende is apparently absent. The groundmass contains an interstitial substance which is yellowish, granular in ordinary light, isotropic and devoid of cleavage. In this and in the Castletown monchiquites there are colourless skeleton crystals, sometimes feathery but often comb-like, with branches set at right angles on a main stem; they may be apatite or feldspar.

The dyke at Toftcarl contains a considerable amount of dark brown hornblende and some feldspar, in addition to olivine and augite, and accordingly we may regard it as a camptonite. The olivine is decomposed; the augite and hornblende are both idiomorphic, and when they occur in parallel growth, as frequently happens, the amphibole is peripheral. In this rock also ocelli are found, consisting of radiate branching feldspars and prismatic brown hornblende. Many of the latter are hollow, with long tubular central cavities. Irregular areas of calcite fill miarolitic spaces in the interior of the ocelli.

* "The Geology of the Seaboard of Mid-Argyll," *Mem. Geol. Surv.*, 1909, p. 90.

The occurrence of nepheline-basalts along with monchiquites and camptonites in the north-east of Caithness is a fact of considerable interest in British petrography. It has been known for some time that there is a large suite of dykes of the camptonite-monchiquite-alnoite series in the Orkneys,* but no nepheline-bearing rocks have yet been reported from the more northern county. Two questions arise for discussion, viz.—whether the rocks which fill the dykes have a close connection with those in the Duncansby neck, and what the age of the igneous rocks may be.

The similarity between the nepheline-basalt and the monchiquite dykes is very great; where both series contain only a decomposed glassy base they are almost identical in their minerals and structures. That nepheline occasionally occurs in the basalt presents no real difficulty, for it is certain that the base of the monchiquites is rich in soda, and many petrologists believe their analcite to be primary. Moreover, primary nepheline has been found in monchiquites in Madagascar by Lacroix,† and more recently nepheline-monchiquites and nepheline-ouachitites have been described by the officers of the Geological Survey from Colonsay and Mull.‡

The only other nepheline-basalts which are known to occur in Britain are those of Lower Carboniferous age at Chesters quarry and Limplum in East Lothian; § these are accompanied by monchiquites but not by camptonites; and at Coire Bà, near Kinlochleven, Mr. W. B. Wright has recently found a nepheline basalt invading the agglomerate of a neck, but the age of this rock is as yet uncertain.

The trap dykes of the Orkneys have a general north-east to east-north-east direction. This is observable also in the dykes of Caithness, and in the arrangement of the necks at Duncansby it is possible to remark a similar orientation. We consider it is extremely probable that the trap dykes of the Orkneys and Caithness and the Duncansby necks have originated from the same magma.

Although the dykes have been regarded as Tertiary, there are no very cogent reasons to support this conclusion.¶ Their wide distribution and the uniformity of their trend would lead us to believe that they belong to an epoch when a considerable area of the north-east of Scotland was underlain by a basic magma. Evidence of volcanic activity in this district, at a date posterior to the deposit of the John o' Groat's Beds, is provided by four sets of lavas and ash-beds in Orkney and in Shetland, all belonging to the Devonian and all presumably distinct.

In Deerness and in Shapinsay, Orkney, there are lava-flows, ash-beds, and sills near the base of the John o' Groat's series.¶¶ The

* J. S. Flett, "The Trap Dykes of the Orkneys," *Trans. Roy. Soc. Edin.*, vol. xxxix. p. 865, 1900.

† A. Lacroix, "Matériaux pour la Minéralogie de Madagascar," *Nouv. Archives du Muséum*, vol. iv. p. 1 (1902), and vol. v. p. 171 (1903).

‡ "The Geology of Colonsay, Oronsay, and the Ross of Mull," *Mem. Geol. Surv.*, 1911.

§ E. B. Bailey, "Summary of Progress for 1908," *Mem. Geol. Surv.*, 1909, p. 45.

¶ J. S. Flett, *loc. cit.*, p. 872.

¶¶ B. N. Peach and J. Horne, *Proc. Roy. Phy. Soc. Edin.*, vol. v., 1880, p. 340.

rocks are all basalts and diabases.* At the base of the Upper Old Red Sandstone of Hoy, in Orkney, there is a considerable manifestation of volcanic activity, as was shown by Sir Archibald Geikie.† Basaltic lavas form the platform on which the Old Man of Hoy stands, and a little to the north-east of this there are necks filled with agglomerate. On the Sound of Noss,‡ in Bressay, in Shetland, there is a neck and a single ash-bed which were discovered by Peach and Horne; the rocks again are of basaltic character, and the fossils which have been obtained in Bressay indicate an Upper Old Red Sandstone age § for the whole group. Lastly there are on the west side of Shetland || great eruptions of andesitic, basaltic, and rhyolitic character; the age of this series is unknown.

No interbedded volcanic rocks are known in the Old Red Sandstone of Caithness, and the absence of lavas in the John o' Groat's series makes it less probable than might otherwise appear that this neck belongs to the first of the groups enumerated above. Sir Archibald Geikie has assigned the Duncansby neck to the period of volcanic activity which ushered in the deposition of the Upper Old Red Sandstones of Hoy.¶ These sandstones form Dunnet Head, about ten miles to the east of Duncansby, and there is a neck at Brough which penetrates these rocks; but the character of the material in the Brough neck is quite distinct from that which occurs at Duncansby. Professor Rosenbusch ** considers that the nepheline-basalts belong to a group which has no distinct affinities with the "felspar-basalts"; but in East Lothian the nepheline-basalts are part of a series in which ordinary olivine-basalts occur in considerable numbers. Till the volcanic rocks of Hoy have been fully investigated, it is impossible to regard the correlation of the Duncansby neck with that series as more than conjectural. No evidence is known which would lead us to correlate the Duncansby necks with any of the volcanic outbursts which have left their traces in the Old Red Rocks of Shetland.

If the dykes and the necks at Duncansby be of the same epoch, they belong to a series which has its centre in the Orkneys or to the west of these, for the dykes are far most abundant on the west side of Orkney; they are rare in Caithness, where they occur only in the north-east, while in the south and west of that county they have not been found, and they are not known in Sutherlandshire. The whole question of the age of these rocks is still very obscure, and the possibility that they are really Tertiary cannot be definitely excluded. J. S. F.

* J. S. Flett, "The Old Red Sandstone of the Orkneys," *Trans. Roy. Soc. Edin.*, vol. xxxix., 1898, p. 413.

† Sir Archibald Geikie, *Geol. Mag.*, 1878, p. 49; *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 411. "Ancient Volcanoes of Great Britain," vol. i., 1897, p. 350.

‡ B. N. Peach and J. Horne, "The Glaciation of the Shetland Isles," *Quart. Journ. Geol. Soc.*, vol. xxxv., 1879, p. 778.

§ J. S. Flett, "On the Age of the Old Red Sandstone of Shetland," *Trans. Roy. Soc. Edin.*, vol. xlv., 1908, p. 313.

¶ B. N. Peach and J. Horne, "The Old Red Volcanic Rocks of Shetland," *Trans. Roy. Soc. Edin.*, vol. xxxii., 1884, p. 359.

** Sir Archibald Geikie, "On the Old Red Sandstone of Western Europe," *Trans. Roy. Soc. Edin.*, vol. xxviii., 1878, p. 405.

** H. Rosenbusch, "Mikroskopische Physiographie," Band ii., 1908, p. 1422.

CHAPTER XII.

GLACIATION AND GLACIAL DEPOSITS.

THE glacial phenomena of Caithness present certain peculiar features which have attracted the attention of geologists. The most characteristic is the occurrence in the boulder-clay of marine shells and blocks of Mesozoic rocks which have not been found in place within the county. This fossiliferous deposit has well-defined limits, beyond which, in the inland region, we find the normal ground-moraine produced by the local ice. The origin of this shelly boulder-clay gave rise to considerable discussion, for it was suggested by the veteran glacialist, Dr. Jamieson, that it might be due to floating ice.

Among the early observers may be mentioned Mr. John Busby, who detected marine shells in the blue clay in 1802,* Mr. Cleghorn of Wick and Robert Dick of Thurso, both of whom sent collections of shells from this deposit to Hugh Miller.† Special reference ought to be made to C. W. Peach, who was the first to publish lists of the organic remains and the first to recognise the resemblance between the ice-worn blocks of Mesozoic rocks in the boulder-clay and the representatives of these rocks on the coast of Sutherland.‡ He also informed James Croll in 1868 that his researches had led him to the conclusion that the shelly deposit was a product of land ice, and that the ice movement had been from the Moray Firth towards the Atlantic.§

The first exhaustive account of the shelly boulder-clay was furnished by Dr. Jamieson, who, in 1866, gave an admirable description of its physical characters, its distribution, and its organic remains.|| He inferred that the glacial phenomena of Caithness differed from those in the midland region of Scotland in the following particulars :—

1. In that the glaciation of its rocks seems to have been produced by a movement of ice proceeding, not from the interior of the country, but apparently from an external region to the north-west.
2. In its covering of drift, which resembles the old boulder-clay of the

* "Minutes of Observations drawn up in the Course of a Mineralogical Survey of the County of Caithness in 1802," Edinburgh.

† "Rambles of a Geologist; or, Ten Thousand Miles over the Fossiliferous Deposits of Scotland."

‡ C. W. Peach, "On the Fossils of the Boulder Clay of Caithness," *Trans. Roy. Phys. Soc. Edin.*, vol. iii., p. 38; "Further Observations on the Boulder Clay of Caithness with an additional List of Fossils," vol. iii., p. 396; also *Brit. Ass. Rep.*, 1862, *Trans. Geol. Sec.*, p. 83; *Ibid.*, 1865, p. 61.

§ *Geol. Mag.*, 1870, p. 212.

|| "The Glacial Phenomena of Caithness," *Quart. Journ. Geol. Soc.*, vol. xxii., 1866, p. 261.

middle of Scotland in regard to its physical arrangement, but differs therefrom in the prevalence of marine organisms scattered through it.

3. In the absence of glacial-marine beds deposited with the indications of tranquillity that we observe in the regions farther to the south.
4. In the deficiency of valley gravel, and the absence of moraines and gravel hillocks.

He further concluded that the shelly boulder-clay "ought to be referred to the glacial-marine period. A set of marine beds containing arctic shells were probably deposited over the low part of Caithness; and much drifting ice seems to have passed over the district from the north-west, which crushed and destroyed these marine beds, broke the shells, and mixed them up with other superficial debris into that mass of rough pebbly mud which now over-spreads the surface. These marine beds were probably of different ages, the older containing arctic species, the later containing chiefly boreal and southern forms."

Appended to his paper, Dr. Jamieson gave a table of the mollusca from the glacial drift of Caithness, in which he incorporated the lists previously published by C. W. Peach.

The marine origin of the Caithness boulder-clay was disputed in 1870 by Dr. Croll, who regarded it as a product of land ice. He maintained that the organic remains had been borne inland with the ground-moraine from the bed of the Moray Firth and the North Sea. He explained this movement on the supposition that the Scottish ice which filled the basin of the Moray Firth was deflected by the Scandinavian ice-sheet and was compelled to overflow the Caithness plain.*

A list of the foraminifera obtained from the boulder-clay sections near Wick was published by Crosskey and Robertson in 1874,† and a list of the entomostraca from the sections in Wick Bay and Burn of Haster, by Brady and Robertson in the same year.‡

In 1880 Messrs. Peach and Horne spent their annual leave of absence in examining the glacial phenomena of Caithness. Their previous researches in the northern isles had led them to the conclusion that the Shetland group had been over-ridden by the Scandinavian ice-field, and that the Orcadian group had been overflowed by the Scottish ice-sheet moving in a north-westerly direction. They found that in some respects there is a close resemblance between the glacial phenomena of Orkney and those of Caithness. They obtained evidence to prove that the local ice from Sutherland and the hilly ground along the county boundary moved east, north-east, and north, till it debouched on the plain, where it was compelled to veer round to the north-west in accordance with the general movement in the low ground of Caithness. This north-westerly movement across the plain was further demonstrated by the transport of erratics, and by the carry of materials in the glacial drift. A list of the organic remains found in the shelly boulder-clay was

* *Geol. Mag.*, 1870, p. 209 and p. 271.

† "The Post-Tertiary Fossiliferous Beds of Scotland," *Trans. Geol. Soc. Glas.*, vol. iii., p. 126.

‡ "The Post-Tertiary Entomostraca," *Monog. Palæont. Soc.*, vol. xxviii., p. 7.

given, the existence of moraines due to the later glaciers was indicated, and a striae map (Fig. 24), showing the direction of ice-flow, was appended to the paper.*

GLACIATION.

The inland limit of the shelly boulder-clay is approximately marked by a line extending from the south coast at Berriedale northwards to Achnaclyth on the Dunbeath Water, thence curving round by Dall on the Loop Burn to the Thurso River between Strathmore Lodge and Dirlot Castle. From this point the boundary swings round by Westerdale and Scotscalder Station to Reay on the northern shore. Attention will first be directed to the movement of the local ice in the area to the west of this line, and its behaviour on reaching the inland margin of the shelly boulder-clay (see Sheets 110 and 116).

Local Ice-flow during the Maximum Glaciation.—In the southern region between Scaraben and the watershed of the Langwell Water to the south, the general movement of the ice, as shown by the striae, was east-south-east, but near the coast at Badbea, a deflection to the east-north-east occurred (Sheet 110). Farther north on Beinn nan Coireag—a hill about a mile and a half north from Berriedale—the striae run due north, and on Clais-cairn Hill, within two miles of the mouth of Dunbeath Water, the markings trend N. 20° W. Again, in the upper reaches of the Berriedale and Dunbeath Waters, the markings point east or a few degrees to the north or south of east, that is across the upland plateau towards the coastal belt (Sheet 109). But when we descend the Dunbeath Water to Achnaclyth—about five miles distant from the shore—the striae found on either side of the valley below this point trend in a north-westerly direction (Sheet 110).

In the valley of Strathmore, a similar deflection of the ice-markings is observable. Between Loch More and Strathmore Lodge, in pits by the roadside, striae are exposed pointing east-north-east, and N. 20° E. (Sheet 116). About a quarter of a mile from the loch, in the direction of Strathmore Lodge, several instances have been re-recorded, trending N. 5° E. Farther down the valley and a little way east from the Lodge, ice-markings were found, pointing north-north-east and north-west, on the same glaciated surface, beneath a thin covering of boulder-clay. The locality where these “cross-hatches” occur is near the inland limit of the shelly boulder-clay.

Again, on the moorland plateau between Altnabreac and Scotscalder Station, striae are not readily found owing to the widespread covering of peat, but a few examples show that in the area traversed by the local ice, the movement varied from east to E. 35° N. (Sheet 115). On reaching the inward margin of the shelly drift near Scotscalder (Sheet 116), marked deflection again appears, for in the long railway cutting west from that station several instances were recorded pointing N. 5° W., N. 20° W., and north-west. Towards the middle of the cutting, on the south side, “cross-hatches” were observed trending north and north-west, evidently due to fluctuations in the movement of the local ice and that which produced the shelly drift.

* “The Glaciation of Caithness,” *Proc. Roy. Phys. Soc. Edin.*, vol. vi., 1881, p. 316.

In the north-west part of the county, between Loch Shurrery and the coast at Reay, the movement of the local ice was towards the north-

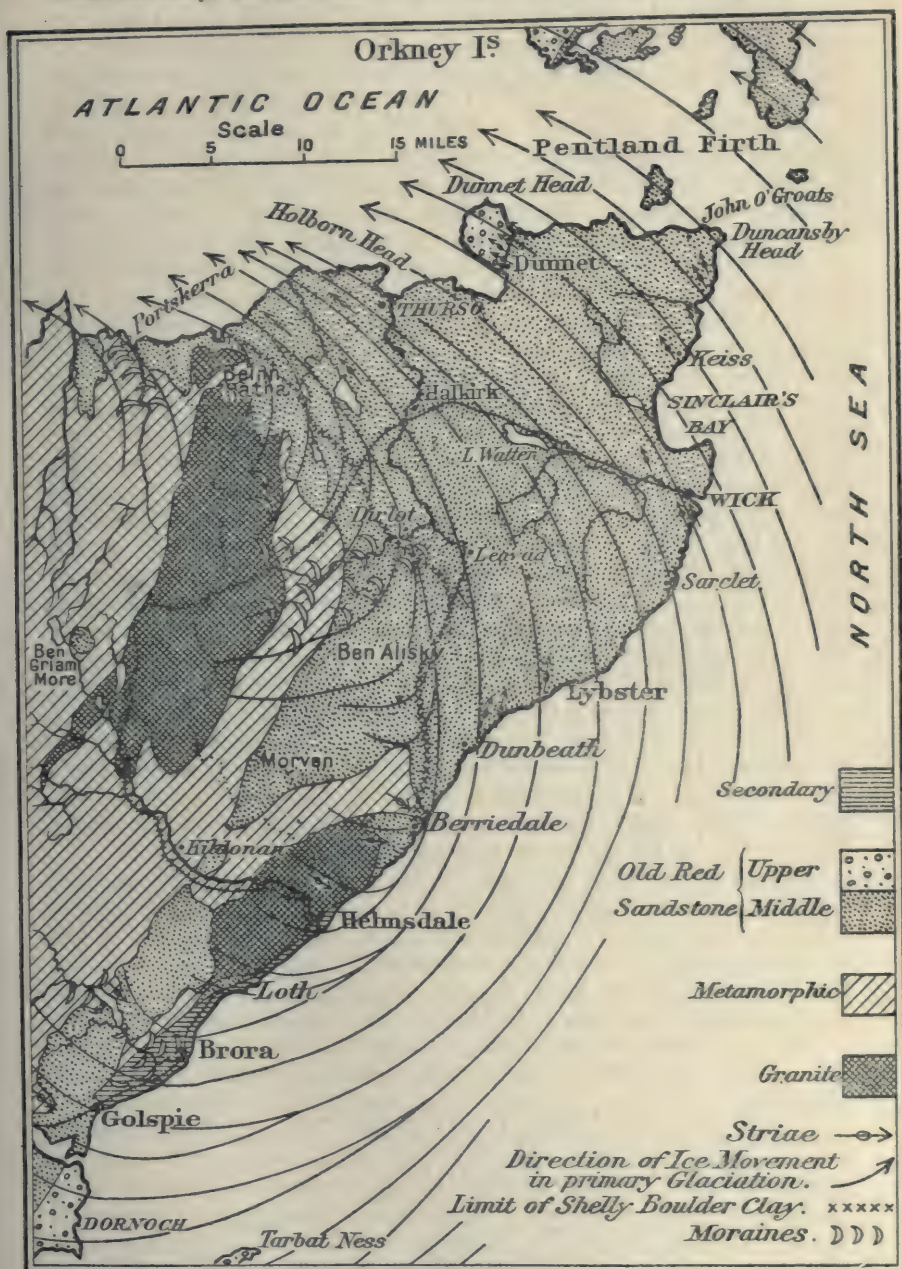


FIG. 24.—Map illustrating the Glaciation of Caithness.

(After Peach and Horne, *Proc. Roy. Phys. Soc. Edin.*, vol. vi., 1881, p. 321.)

north-east. Thus about a mile and a half to the west of that loch, striae were recorded on a granitic breccia, pointing N. 15° E.

About a mile farther east, near Achsteenclate, similar evidence was obtained. Again, on Beinn nam Bad Mòr (952 ft.)—a hill about 3 miles west from Loch Shurrery—the general trend of the ice markings is N. 10° to 20° E. Farther north, on the north slope of Beinn Ràtha (795 ft.), about 2 miles north-west from Reay, the instances point N. 10° E., N., and N. 10° W., this locality being not far to the west of the limit of the shelly boulder clay. Additional evidence might be advanced to show that the local ice in this part of the county moved in a north-north-east or northerly direction, but these isolated examples are sufficient for the purpose. After crossing the limit of the shelly drift between Shurrery and Reay, there is conclusive evidence of the deflection of the local ice towards the north-west. For in the tract drained by the Achvarasdal Burn and its tributaries northwards to Sandside Bay, the striae point north-north-west, north-west, and W. 15° N., in accordance with the movement across the Caithness plain.

Ice-flow during the Maximum Glaciation within the Area of the Shelly Boulder-clay.—Throughout the hilly tract (in Sheet 110), lying to the north of Latheron and Lybster in the south part of the county, the general trend of the striae is about N. 20° W. with little deviation from this direction. They occur at all levels, having been observed on the top of Ben-a-chielt (942 ft.), so that the ice which moved inland from the Moray Firth must have overflowed all the high ground in this portion of Caithness. Striated surfaces are not well-preserved if the rock has been long exposed to weathering, but are readily found where a covering of peat has been recently removed. Fine examples of “cross-hatches” produced by the two ice-movements—one set trending N. 20° W., and the other about N. 30° E.—are to be found on the west shore of Loch Stemster, about 6 miles north from Janets-town (Sheet 110). This locality is near the margin of the shelly drift. The preservation of these striae is due to the fact that they have been laid bare only within the last century, owing to the lowering of the level of the loch for the purpose of obtaining marl.

Similar evidence is obtained in the tract between Lybster and Sarclet, numerous instances having been recorded in the hilly ground adjoining the coast. Some examples pointing a few degrees to the east of north have been noted in the coastal fringe between Achastle and Mid Clyth, and on the south slope of Mid Clyth Hill, but these may be due to a slight deflection of the Moray Firth ice on reaching the land.

Along the eastern coast between Noss Head and Ires Goe, 3 miles south of Wick, the striae run in a north-westerly direction. Thus at Noss Head the trend is north-west, at Staxigoe north-north-west, at South Head north-west, at Castle of Old Wick north-west to north-north-west, at The Brough north-west to north-north-west, at Girston north-north-west, and at Ires Goe N. 10° W. to north-north-west. One of the best instances occurs on the cliff top opposite the Old Man of Wick. At this locality the flagstones dip inland (N. 30° W.), at a gentle angle, thereby forming small escarpments along the outcrops of the successive beds. On the dip slopes the ice-markings point N. 10° to 20° W., but opposite each escarpment they are deflected, the trend becoming still more northerly, while in the succeeding dip slope the normal direction is resumed. The slight deflections observable in these small escarpments point to an agent moving inland

from the south-east. Still farther north along the eastern coast between Sinclair's Bay and Duncansby Head, Dr. Jamieson found striae running in a south-easterly and north-westerly direction. On the cliff-top, near Skirsa Head, he recorded instances pointing W. 25° N., in the bed of the Freswick Burn, N. 35° to 40° W., and at Keiss, N. 35° to 40° W.

A glance at the map will show that in the northern tract embracing East Mey, Barrock, Brough, and Dunnet Hill, where striated surfaces are comparatively numerous, the movement varied from west-north-west to north-west. But when we proceed westwards to the area between Castletown and Thurso the trend is more northerly, varying from N. 5° to 15° W.

Throughout the central plain, between the valley of the Thurso River and the east coast, striated surfaces are not abundant, owing to the extensive covering of peat and glacial drift, but various examples have been recorded indicating a movement in a north-west or west-north-west direction. In one special area, however, round Loch Watten "cross-hatches" are of common occurrence. These point to ice-movements in widely different directions, and are of special interest, as they are situated about six miles to the east of the inland margin of the shelly boulder-clay. These and other instances are given in the subjoined tables :—

Localities South from Loch Watten.

1. Wester Watten, about half a mile south from Loch Watten, in flagstone quarry under thin drift, E.N.E. and N.N.E.
2. Quarry half-way between Wester Watten and Laid under thin drift, W. 15° N. and N.
3. Flagstone quarry, one-third of a mile south of Laid at Hill of Houstry, N. 40° W. and N.N.E.
4. Houstry of Dunn, 100 yds. west from farmhouse, N.W. and E.N.E. ; another locality, about 300 yds. to the south, N.W. and N.E.

It is worthy of note that to the south and west of the striated surfaces given in the foregoing table, numerous quarries furnish examples pointing N. 35° W. and N.W., in accordance with the general ice-movement which gave rise to the shelly boulder-clay.

Localities North from Loch Watten.

1. Stonehane quarry, about a mile to the north of Loch Watten, and over 100 ft. above the level of the lake, at least three sets of striae varying from W. to N., the latter being the most recent.
2. Lynegar quarry, ice-markings pointing N.

As all these instances occur at a distance of several miles from the inland margin of the shelly boulder-clay, it is difficult to explain them by differential movement of the two opposing ice-streams. It seems more reasonable to regard the north-easterly set at least, as having been produced by the local ice, either before or after the maximum glaciation. In the section dealing with morainic deposits (p. 129), the striae running in this direction are associated with the later glaciation of the region.

In the district between Thurso and Reay (Sheet 115), numerous examples have been recorded, pointing to a movement in a west-north-west or north-west direction. On the surface of the flagstones, in the Achscrabster quarries, the trend is W. 25° N. Here blocks

have been broken off the flagstones by the ice in its passage over them, which are tilted at a gentle angle towards the north-west, while the flags themselves have been bent over in the same direction. In the Jamestown quarries, about two miles south-west of Thurso, the prevalent trend is W. 20° N., but on the same rock-surface there is a fainter set pointing north-east. The latter seem to be of older date, as they have been nearly effaced by the north-west movement. At Shebster the trend is W. 30° N.; at Westfield, near the Forss Water, W. 20° to 25° N.; and at Reay, as noted by Jamieson, N.W. and W. 35° N.

The evidence now adduced regarding the direction of the ice-flow throughout the area occupied by the shelly boulder-clay proves the accuracy of Jamieson's conclusion that these striae could not have been caused by glacier action proceeding from the interior of the country towards the present coast. It further shows that the north-westerly movement must have been quite independent of the local ice-stream. Indeed, it was so powerful that the local ice was deflected and compelled to veer round towards the north-west. At the same time, it is highly probable that before the *mer de glace*, which ultimately filled the North Sea, attained its full development, the local ice may have spread over part of the Caithness plain. Some evidence has been obtained which lends support to this view, for in the bores at Leavad a boulder-clay with local stones was found beneath the shelly till (p. 132). On the other hand, there seem to be grounds for the contention that, after the retreat of the Scandinavian ice-sheet, the inland ice of Sutherland and Caithness may have invaded part of the area occupied by the shelly boulder-clay.

BOULDER CLAY.

As might be expected, the boulder-clay in Caithness presents two well-marked types, the boundary between them coinciding generally with the junction line of the two opposing ice-streams, as indicated by the striae. The ground-moraine produced by the local ice is a reddish or brown stony clay, with no shells, the stones being derived solely from the area traversed by the inland ice. The second type consists of a dark grey or blue stony clay, with fragments of shells scattered through it, and containing a number of blocks of rocks which are foreign to the district, in addition to the stones of local origin.

Excellent sections of the local ground-moraine are to be found at the south end of the county beyond Berriedale, on the northern shore west from Reay, and in the midland area in the basin of the Thurso River above Strathmore Lodge. The sections on the coast between the Ord and Berriedale (Sheets 109, 110) reveal a reddish-brown gritty clay, with striated stones, comprising breccia, grit, flags and shales, quartzite, biotite-gneiss, and pink granite, all of which occur in place in the neighbourhood. Here, as already indicated, the local ice moved east-south-east, till, as it approached the coast near Badbea, it was deflected a few degrees to the north of east. A similar deposit is to be found in the Berriedale Water, where the hard sandy boulder-clay has been derived from the rocks inland. It contains numerous blocks and smaller fragments of granite and schist, and varies in colour according to the nature of the floor over which the ice advanced.

Boulders of conglomerate have been carried eastward along the south flank of Scaraben.

Regarding the sections in the lower part of the Berriedale Water, Jamieson remarked that while most of the drift has a reddish-brown colour, there is also a mixture of dark bluish-grey material, in which he found nine or ten small pieces of shell and a fragment of a *Balanus*.* He also noted in it pieces of shelly limestone and of dark sandstone containing lignite. This commingling of the two deposits occurs near the margin of the shelly drift where the opposing ice-streams met.

In the basin of the Thurso River, above Strathmore Lodge, there are exposures of reddish-brown gritty clay sometimes covered by moraines. A clear section is to be found at the bend in the river above the lodge, where the stones consist of Moine schists, pink granite, felsite, and red flags, many of them well striated. Not far below the lodge the dark-grey boulder-clay, with fragments of shells and blocks of Mesozoic rocks, makes its appearance. The change in the character of the ground-moraine occurs where the striae indicate the deflection of the local ice by the sheet moving in a north-west direction.

Again, in the north-west part of the county, the reddish-brown till is well developed. It rests on the grey flags in the Burn of Isauld and at Reay, and it forms high cliffs along the shore between Sandside Bay and the county boundary, where it is covered by a series of moraines belonging to the later glaciation. In these sections no fragments of marine shells have been detected, and the stones are of local origin.

The descriptions of the distribution and physical characters of the shelly boulder-clay first given by Dr. Jamieson have been confirmed by later observers. This deposit does not form a sheet of uniform thickness across the Caithness plain. It is best developed in the valleys which probably occupy preglacial hollows and in the bays along the seashore. It thins out on the rising ground, and on some of the ridges it disappears, as, for instance, on Spital Hill, Holborn Hill, and other eminences in the north of the county. In the south-eastern districts, between Latheron and Loch Stemster, and between the Hill of Mid Clyth and the Hill of Ulbster, there are large driftless areas. On referring to Sheet 110 it will be seen how the shelly drift covers a narrow strip of ground along the course of Latheronwheel Burn with driftless ridges on either side. Excellent sections of this deposit are to be found in the Dunbeath Water, Thurso River, Forss Water, in Wick Bay, and at Scrabster Harbour. At the last of these localities its thickness is estimated at 100 ft.

The physical characters of this deposit are remarkably uniform. It consists of a tenacious gritty clay of a dark leaden-grey or blue colour when moist, but sometimes weathering with a brown colour in the upper part of the sections. Smoothed and striated stones are scattered irregularly through the mass. They usually vary in size from an inch to a foot in diameter, but blocks from two to three feet across are occasionally to be found. Frequently the stones are arranged with their long axes parallel with the striae on the underlying ice-worn rock-surfaces—that is in a general north-west or north-north-west direction. There is a marked absence of stratification in the deposit, though, in places, lenticular seams of sand are intercalated in it. Finally, a characteristic feature is the presence of

* *Quart. Journ. Geol. Soc.*, vol. xxii., 1866, p. 270.

marine shells, usually in a fragmentary form, rarely entire, which are smoothed and striated like the stones associated with them.

The assemblage of stones in the shelly till is noteworthy. The most abundant rock debris has been derived from the Caithness Flagstone series. The smaller stones and minute fragments are almost wholly composed of this material. The bands of sandstone interbedded with the flagstones have also supplied blocks for this deposit. But the ingredients that arrest the attention are those which are foreign to the Caithness plain. Of these may be mentioned siliceous schist and garnetiferous muscovite-biotite-schist, like the members of the Moine Series in Ross-shire, augen-gneiss or foliated granite, like the Inchbae mass in the same county, hornblende-schist, granite, Oolitic limestone, Oolitic brecciated conglomerate, Jurassic sandstone, together with chalk and chalk flint. Some pieces of jet were collected by Mr. C. W. Peach in the sections at Wick, and some specimens of belemnites were found by him at Wick and in the Thurso River. Several blocks of fossil wood were detected in the shelly drift by Messrs. Peach and Horne, which are identical with those obtained by them in the shelly boulder-clay in Odin Bay, Stronsay, Orkney. A similar rock is embedded in the Oolitic shales in Sutherlandshire, where it is burned for lime.*

It may now be observed that, with the exception of chalk and chalk flints, the blocks of igneous, metamorphic, and Mesozoic rocks occurring in the Caithness shelly till might have been derived from the eastern portions of the counties of Sutherland and Ross. And though Cretaceous rocks have not been recorded in place on the mainland around the Moray Firth, they are believed to exist in the bed of the Firth. The evidence, therefore, points to the carriage of materials from the Moray Firth basin in a north-westerly direction across the Caithness plain. This conclusion is supported by the transport of stones of local origin within the county in a similar direction. Thus blocks of the Sarclet Conglomerate, exposed on the shore about four miles from Wick, have been traced inland in the direction of Thurso, and debris of grey flagstone has been carried across the Brough fault from the Rattar district on to the higher ground around Dunnet Hill, occupied by the Upper Old Red Sandstone. In the section dealing with erratic blocks now found on the surface (p. 130) confirmatory evidence will be adduced of this north-west movement during the maximum glaciation.

The observations made by Dr. Jamieson regarding the shells in this deposit, their state of preservation and the commonest forms, have been supported by later research. Although they have been smoothed and striated like stones in the drift, a considerable list of mollusca has been compiled from the fragmentary remains. The most abundant forms are *Cyprina islandica*, *Maetra solida*, *Mya truncata*, *Turritella unguolina*, *Astarte elliptica*, *A. borealis*. In some rare cases more complete specimens have been obtained. Dr. Jamieson collected "one entire valve of *Astarte borealis*, another of *A. elliptica*, and two small ones of *A. compressa*, likewise a specimen of *Natica nitida*, and another of *N. islandica*, both almost perfect." † He further states that Mr. C. W. Peach "got a specimen of *Anomia*, with

* *Proc. Roy. Phys. Soc. Edin.*, vol. vi., 1881, p. 336.

† *Quart. Journ. Geol. Soc.*, vol. xxii., 1866, p. 267.

both valves complete, in a fine state of preservation, and this was in the drift containing the usual assemblage of ice-worn stones and broken shells."* This specimen was found protected in the hollow of a stone.

Among the mollusca only a few specimens characteristic of the littoral zone have been found; those collected by Mr. C. W. Peach comprising *Purpura lapillus*, *Patella vulgata*, *Mytilus*, and *Tapes pullastra*. This fact is suggestive, for the forms whose habitat lay in deeper water would naturally be more abundant in the ground-moraine of the ice that passed over the floor of the Moray Firth. In this connection reference may be made to the limited development of shelving beaches on the east coast of Caithness. The prominent feature of the coastal belt is the line of rock cliffs between the Ord and Duncansby Head, with the exception of some sandy bays.†

MORAINES AND GRAVELS.

Within the county of Caithness there is conclusive evidence of the existence of moraines, gravel heaps, and ridges which belong to the later glaciation. During their holiday work in the county in 1880 Messrs. Peach and Horne traced these later accumulations down Strathmore to the edge of the Caithness plain at Dalemor, about a mile to the east of Dirlot Castle. They noted a gradual change in the character of the materials when followed down the valley. Thus around Dalnawillan Lodge—about eight miles up the stream from Dirlot—where the moraines are well developed, the deposit consists of an admixture of sand and clay with rounded and subangular stones occasionally striated. But near Strathmore Lodge and Dirlot it consists of sand and gravel, more or less stratified, with occasional blocks of conglomerate and sandstone, measuring 3 ft. across. They called attention to one prominent ridge, varying in height from 20 to 30 ft., which extends from the farmhouse of Dirlot to Dalemor, a distance of nearly a mile. They noted that these accumulations rest both on the reddish-brown local boulder-clay and the dark grey shelly drift, so that there can be no doubt that they belong to a later phase of the glaciation of the region.‡

The detailed mapping of the region has proved the existence of moraines resting partly on the ground-moraine of the local ice and partly on the shelly boulder-clay at various localities between Berriedale and Reay. It has further shown the extension of mounds and ridges of sand and gravel far to the east of the inland limit of the shelly till, which, in the opinion of Dr. Peach, have been formed by the confluent glaciers of Caithness and Sutherland after the retirement of the Moray Firth ice.

In the south part of the county (Sheet 110), moraine-like mounds

* *Quart. Journ. Geol. Soc.*, vol. xxii., 1866, p. 267.

† In the paper by Messrs. Peach and Horne a list of the organic remains found in the shelly boulder-clay of Caithness is given. In addition to the mollusca, it includes representatives of other groups, such as ostracoda, echinodermata, annelida, and foraminifera. This list was prepared from papers by Mr. C. W. Peach, Messrs. Crosskey and Robertson, and by Messrs. Brady, Crosskey, and Robertson. The private collection of C. W. Peach was also re-examined by Dr. B. N. Peach. See *Proc. Roy. Phys. Soc. Edin.*, vol. vi., 1881, p. 338.

‡ *Proc. Roy. Phys. Soc. Edin.*, vol. vi., 1881, p. 344.

occur along the course of the Langwell Water from a point below Wag to within three miles of the sea, and again on both sides of the Berriedale Water above An Dùn. In the latter case the morainic material must have been deposited on the boulder-clay that filled the channel of the Berriedale Water before the latter was re-excavated by the stream. A line of moraines also flanks the eastern side of Beinn nan Coireag about a mile and a half north from Berriedale—and extends northwards from Newport for a distance of more than a mile.

In the Reay district (Sheet 115), in the north of the county, the confluent glacier sent lobes of ice down each valley, as moraines are to be found resting on boulder-clay almost down to sea-level. Not far to the west of Reay prominent moraines cap the reddish-brown boulder-clay along the precipitous cliffs washed by the sea. In the Achvarasdal Burn there is a group of these mounds on the south side of the old drained lake, now represented by an alluvial flat, a little to the south-east of Borlum, within the limit of the shelly drift. Another lobe seems to have passed down the Forss Water to the west of the Dorrery Hills. The moraines left by this ice-stream are particularly well developed about Loch Shurrery, and are traceable to a point below Brubster village, while fluvio-glacial gravels are seen to overlies boulder-clay exposed in the bluffs bounding the Forss Water near Milton. Kamiform mounds occur in considerable numbers to the south and east of that locality and to the north of Achscrabster quarries.

Reference has already been made to the mounds and ridges of sand and gravel near Dirlot. Similar deposits occur at intervals along the broad valley of the Thurso River between Westerdale and the town of Thurso (Sheet 116). They are mostly arranged in the form of mounds, but few sections are to be found. The materials where exposed consist of gravel and sand frequently stratified, the stones comprising sandstone of local origin, schists, and granite. For example, at Olgrinmore, three miles south-south-west of Halkirk, mounds of water-worn gravel appear on the west side of the river. Again, on the east of the stream, about a mile south of that village, the drift has a marked hummocky contour. Farther down the valley at the Picts House and Chapel, near Skinnet, there is a series of grass-covered mounds, circular in shape or elongated in a north-east and south-west direction. They appear to be kames, but no section of the material was observed in the course of the mapping by the Geological Survey. South from Todholes, on the east bank of the river, a deposit of fine sand and gravel, sometimes in the form of kames, rests upon the shelly boulder-clay. Still farther north, near Geiselittle, kamiform ridges and many small irregular mounds have been recorded, while to the west of that farmhouse, at a point about a mile and a half to the south of Thurso, there is a high terrace of gravelly drift with a hummocky contour superimposed on shelly boulder-clay.

A more continuous series of gravel mounds and hummocks has been traced from Dalemore on the Thurso River up Strath Beg to Torran, thence by the Meeting House into the valley of the Acharole Burn to Watten, a distance of about eight miles. Near the Meeting House these glacial gravels cross a low watershed at an elevation of about 300 ft. between the tributaries of the Thurso and Wick rivers.

Sections in these mounds are not common ; those near Shielton and Ballacharn expose false-bedded sand and gravel, with abundant pebbles of dark green and red sandstone, and a few of coarse granite. They can be seen to rest on shelly boulder-clay. In the opinion of Mr. Carruthers they are probably kamiform deposits, laid down by a subglacial stream.

A still greater development of these accumulations extends for a distance of seven miles down the Wick valley from Watten to the town of Wick. They occur as mounds or ridges, yielding few sections, but in some excavations the materials consist of sand and gravel, more or less stratified, and morainic matter, both resting on shelly boulder-clay. They are regarded by Dr. Peach as moraines. Perhaps the best marked examples are to be found on either side of Bilbster House on the south side of the valley, and especially about one and a half miles to the west-north-west of that house. Here the mounds are separated from each other by peaty flats, evidently marking the sites of old lochans or kettle-holes. A conspicuous moraine-dammed lochan occurs near Borgie, which was drained for marl, and in the course of the operations the remains of *Bos longifrons* were obtained from it. The deposits consist partly of coarse gravel and partly of morainic material, and at the bend in the Wick River, near Loch Watten, they are seen to rest on stiff shelly boulder-clay.

Farther down the valley the Wick River flows through the alluvium of a silted-up lake, the ground on either side having a hummocky contour due to gravel mounds and kames. One of these ridges, nearly half a mile in length, is bounded by the alluvium, and exposes, in a large opening, sand and gravel with stratification parallel with the slopes of the ridge. South of the river occasional mounds of drift, elongated in an east-south-east and west-north-west direction, occur as far to the south as the Burn of Haster (Achairn Burn). Near Lower Achairn gravelly clay is superimposed on shelly boulder-clay with *Cyprina islandica*, *Pecten maximus*, *Dentalium*, *Aporrhais*, and other forms. An overflow channel, associated with these phenomena, occurs to the east of Stirkoke House, and runs for about a mile in a northerly direction, parallel with the Burn of Haster (Achairn Burn).

Eastwards beyond the site of the silted-up lake the river has cut a small gorge, probably round the edge of a lobe of ice. Farther down moraine-like mounds appear on both sides of the stream, those on the north side being known as the Hills of Gillock, and one to the south as the Fairy Hillock.

Returning to the area west-north-west from Watten we find moraine-like mounds near Old Hall and Ouglassy presenting features similar to those just described in the Wick valley.

The phenomena connected with these later accumulations and the cross-striae in the district of Loch Watten are accounted for by Dr. Peach in the following manner. The confluent glacier of Sutherland and Caithness which passed eastward down Strathmore and across the plateau to the south of the Dorrery Hills sent one lobe of ice down the Thurso valley to within a mile of that town. Another lobe crossed the low watershed between the Thurso and Wick river-systems east from Torran. On reaching the depression

in which Loch Watten lies, the ice-stream forked, one branch descending the Wick valley and reaching the sea-level at Wick and probably at Ackergill in Sinclair's Bay. A portion of this lobe probably extended as far as the Loch of Wester. Another branch moved in a westerly direction up the Loch Watten depression, past Loch Scarmclate, and may have coalesced with the Thurso valley lobe through the low pass at Georgemas. A small branch of this lobe may have moved northwards by Corsback, thereby accounting for the scattered moraine-like mounds and deserted channels, which are a common feature in the Bowermadden district about four miles north from Loch Watten.

According to Dr. Peach there is some evidence in favour of the view that the area of high ground culminating in the Hill of Olig (463 ft.) nursed small independent glaciers. Small groups of moraine-like mounds are found at various localities in the hollows of this district. Perhaps the largest of this isolated group of local glaciers descended the hollow now drained by the stream that flows north-north-west into Murkle Bay, for a line of these drift heaps can be traced down the slope to the point where the burn is crossed by the Thurso and Castletown road. The material, consisting of large ovoid blocks of Caithness flagstone, is laid bare in the road cutting. Farther down, where the burn makes a sharp bend to the north-east towards Murkle Bay, a horseshoe-shaped terminal moraine is intersected by the stream.

Even Dunnet Hill (398 ft.) seems to have formed a small independent ice-centre during the later glaciation, for a few moraine mounds are seen to rest on shelly boulder-clay in the small stream that enters the sea at the edge of Sheet 116 due north from Brough village.

ERRATICS.

To the east of the limit of the shelly boulder-clay various erratics have been found resting sometimes on the shelly drift and sometimes on the solid rock, which furnish important evidence of the north-westerly movement of the ice during the maximum glaciation. Erratic blocks foreign to the Caithness plain were recognised by Dick, C. W. Peach, Jamieson, Peach and Horne, in the course of their early investigations, and numerous additional examples were recorded during the detailed mapping of the region. But by far the most important instance is the large transported mass of Cretaceous rocks discovered by Mr. Tait of the Geological Survey, and proved by bores to be superimposed on shelly drift, of which a detailed description is given in the sequel.

Among the boulders foreign to the district may be mentioned biotite- and hornblende-granite, augen-gneiss or foliated granite, muscovite-biotite-gneiss, siliceous Moine schist, quartzite, Cambrian Pipe-rock, Jurassic sandstone, chalk and chalk flint. In many cases the smaller foreign blocks have been removed from the fields during the reclamation of the land, and have been used for building dykes.

Some examples may be given to show the wide distribution of these boulders. Those of granite have been found near Weydale Moss a mile and a half south-south-east from Thurso, on the Hill of Olig, Sordale Hill, Spital Hill, near Camster, two miles north from

Loch Watten, and at Syster, three miles east-south-east of Dunnet. The erratics of augen-gneiss cover an equally wide area. They have been noted in the north between Brough and Dunnet, between Greenvale and Barrock Free Church, on the east shore of Loch Scarmclate near Bower Station, and at a spot between Flex and Thuster, about five miles west from Wick. The boulders of Cambrian Pipe-rock were first detected in the course of the Geological Survey of the district. The recorded instances occur in the northern part of the county, as for instance in a field between Greenvale and Barrock Free Church, near Barrock village, and half a mile south-south-west from Phillips Mains near the Hill of Rigifa'. A block of Jurassic sandstone with lamellibranchs has been observed at Achlure, half a mile north-north-west from Achanarras quarry, and fragments of chalk and chalk flints are of common occurrence over the tract between Noss Head and Wick.

Boulders of Old Red Sandstone and Old Red Conglomerate have a wide distribution. The peculiar conglomerate found in place at Sarclet, four miles south from Wick, has supplied erratics which have been traced across the county to the village of Ham on the north coast, and to a point between Holborn Head and Brims Ness, west from Thurso.

A boulder of andesite has been noted on the shore of Loch Meadie, to the north-west of Strathmore Lodge, in the area occupied by moraines belonging to the later glaciation. In Strathmore and in the Reay district numerous *blocs perchés* of local origin are strewn on the moraine heaps. Again an erratic of conglomerate resembling that in place at Houstry, one mile south from Loch Watten, has been recorded at Faulds, about a mile and a half to the north of that loch.

B. N. P., J. H., C. B. C., E. M. A., R. G. C.

TRANSPORTED MASS OF CRETACEOUS SANDSTONE AT LEAVAD.

In 1906 Mr. D. Tait, when examining a collection of stones dredged from the bottom of Wick Harbour, in the possession of Bailie Simpson of Wick, was struck by the appearance of certain rounded masses of fine yellowish sandstone. He recognised their concretionary character and their marked difference from any of the Old Red Sandstone rocks of Caithness. Shortly afterwards he visited the well-known sand-pit at Leavad, three miles south of Spital, which has long been worked as a source of abrasive sand used in the flagstone works of the north of Caithness. In this sand there are many concretionary lumps of sandstone, some of which very closely resemble those that had been found at Wick, and Mr. Tait brought forward the suggestion that the latter were lumps of Secondary sandstone that had been carried inland from the sea-bottom to the south-east of Wick by the action of the ice-sheet. He was inclined at that time to ascribe the Leavad Sandstone to the Jurassic system.*

In 1908 he again visited the Leavad sand-pit and succeeded in obtaining fossils from the concretionary sandstone. These included fragments of cephalopods which were submitted to Dr. Lee and Dr. Kitchin, who determined them as belonging to the Cretaceous.

* D. Tait, "On Egg-shaped Stones dredged from Wick Harbour," *Trans. Edin. Geol. Soc.*, vol. ix., 1907, p. 135.

The pit at Leavad is about 150 yds. long, and on both the east and west sides is bounded by walls of boulder-clay only 2 or 3 ft. thick; sand occurs on both sides of these walls. Moreover, in the working-face of the pit there were visible in 1908 three dyke-like masses of boulder-clay traversing the sandstone. All these dykes had a north and south direction and evidently filled cracks in the sandstone. The clay contained fragments of quartzite, mica-schist and other transported rocks, which proved that it was a true boulder-clay. In view of this evidence it was thought possible that the whole sandstone mass, though undoubtedly of considerable size, might be a glacial erratic, and in order to test this hypothesis, Dr. Horne applied to the Royal Society for a grant of money to enable bores to be put down. Accordingly ten bores were made in and around the sand-pit in July and August, 1910. They were entirely successful, for they proved that the sandstone rested on boulder-clay and is merely a large transported mass.*

The position of the sand-pit and of the bores is represented on the accompanying diagram (Fig. 25). "The chief bore, No. 1, was put down at the northern end of the sand-pit itself, and carried to a depth of 79 ft. In this bore, after passing through 9 ft. of the sand worked in the pit, a bed of dark green clay was met with, somewhat micaceous, and containing foraminifera, iridescent shell fragments, and some small pellets of iron pyrites. There were distinct planes of bedding, although it was impossible to ascertain whether they were disturbed or not. This green clay, alternating with more sandy layers, proved to be 11 ft. 6 ins. in thickness. The bore then passed into a typical shelly boulder-clay, with well-striated pebbles of schist and granite, together with others of Old Red Sandstone, local in origin. With some slight alterations in colour, and the intercalation of three beds of gravel, this boulder-clay continued for the remainder of the bore,† the total thickness of boulder-clay and gravel passed through being 59 ft. 5 ins.

"To determinate the approximate dimensions of the mass, shallow bores were put down along lines ranging north, south, east, and west from No. 1 Bore.

"No. 2 Bore was put down at the south end of the quarry, a few yards outside the limit of the old sand workings. No sand was found, the bore passing almost immediately into the dark green shelly clay, which proved to be 25 ft. 6 ins. thick at this point and rested upon boulder-clay.

"No. 3 Bore was on the north side of the quarry, 100 ft. north of No. 1. No sand was met with, there being 11 ft. of green foraminiferal clay, underlain by shelly boulder-clay. The northern limit of the sand having been passed, No. 4 Bore was put down 50 yds. nearer No. 1, and the sand was reached underneath 8 ft. of moss and boulder-clay.

"No. 5 Bore was put down to the west of the quarry, 100 yds. west of No. 1; boulder-clay only was met with. The bore was stopped

* D. Tait, "On the Occurrence of Cretaceous Fossils in Caithness," *Trans. Edin. Geol. Soc.*, vol. ix., 1908, p. 318. R. G. Carruthers, "On the Occurrence of a Cretaceous Boulder of unusual size, at Leavad, in Caithness"; "Summary of Progress for 1910," *Mem. Geol. Surv.*, 1911, p. 80.

† Mr. Tait records that below the shelly boulder-clay there was a yellowish-green, sandy clay, quite different in character. It is of local origin, and contains principally fragments of Old Red Sandstone derived from the immediate neighbourhood (*Trans. Edin. Geol. Soc.*, vol. x., 1912, p. 2).

10 ft. down, and another (No. 6) was put down, and 50 yds. nearer No. 1. Here the sand was again found, covered by 9 ft. of moss, and dirty sand and gravel.

No. 7 Bore was situated on the east side of the quarry, 100 yds. east from No. 1 Bore. After passing through 10 ft. of moss, brown clay, and gravel, the bore was continued 2 ft. farther into broken sandstone, probably of Old Red Sandstone age.

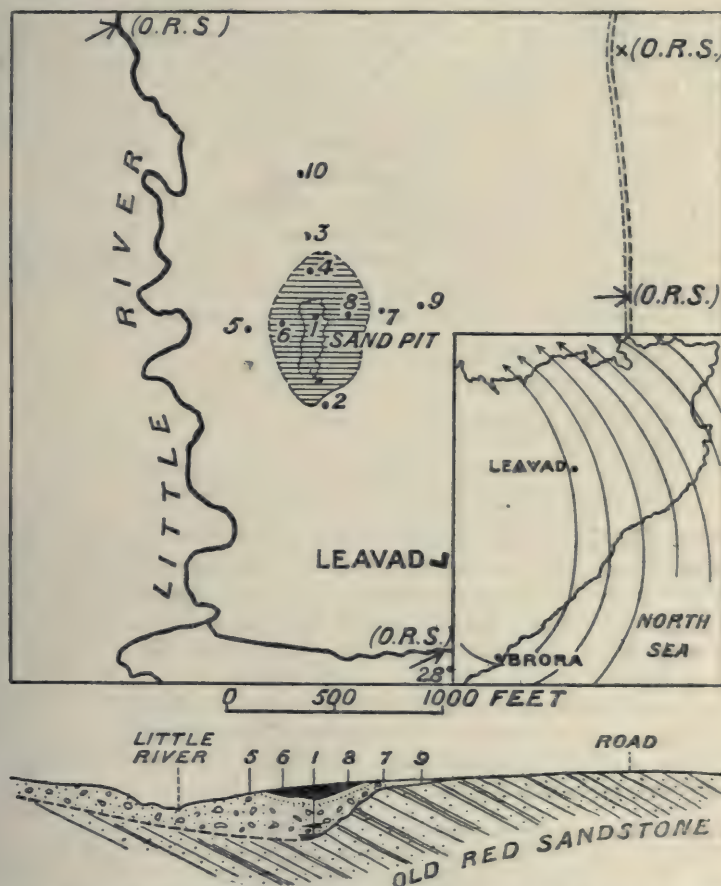


FIG. 25.—Diagram showing the Mode of Occurrence of the Leavad Boulder. The area of sandstone is indicated by horizontal lines. The bores are numbered.

The inset is an outline map showing direction of glaciation in Caithness.

The horizontal section is taken in an east and west direction through the sandpit. The sandstone is black, with boulder-clay underneath. Vertical scale twice horizontal.

No. 8 Bore was then put down 50 yds nearer No. 1, and the sand was again reached underneath 3 ft. of moss and boulder-clay.

As it was possible that the 'broken sandstone' found in No. 7 Bore might be an unweathered portion of the Cretaceous mass, another bore (No. 9) was put down 150 yds. east from No. 1, but broken sandstone was again met with under 2 ft. of moss and boulder-clay. It is, therefore, highly probable that both No. 7 and No. 9 Bores reached

the bed rock of Old Red Sandstone, which is seen outcropping to the east in a quarry by the roadside, and in stream sections to the south and north-west." *

A small exposure of sand similar to that of Leavad is seen at Tacher, half a mile farther north, and, to ascertain whether the two masses were continuous, a final bore (No. 10), was put down 200 yds. north of No. 1. No sand was met with, however, and consequently the Tacher sand belongs to other boulders of the same Cretaceous material.

The Leavad sand is yellow in colour and contains a little mica. The concretions are of rounded or ovoid shape, and sometimes 10 or 12 ft. in diameter. They are composed of hard, durable sandstone, and there can be no doubt that the sand around them has arisen from the decomposition of the softer portions of the sandstone. The fossils occur principally in the concretions.

Dr. Lee has given the following particulars regarding the fossils: "These fossils include lamellibranchs, gasteropods, and cephalopods, only a few being specifically determinable on account of the coarse nature of the matrix. The better-preserved specimens were submitted to Dr. F. L. Kitchin, who determined them as follows:—

Pecten (*Syncyclonema*) *orbicularis*, *J. Sow.*
Pteria (*Oxytoma*) *sp.*
Desmoceras ?
Craspedites *sp.* (probably *sp. nov.*).
Hamites *sp.*
Crioceras *sp.* (fragment illustrating a simply costate stage).
Crioceras *sp.* (fragment illustrating a spinous stage).

"Dr. Kitchin remarks that the fossils are of Cretaceous age, and that the assemblage, taken as a whole, points to a Lower Cretaceous rather than an Upper Cretaceous horizon. He also thinks it probable that they are either Valanginian or Hauterivian, that is, from a lower horizon than those from Moreseat, which were believed by Mr. Jukes-Browne to be of Aptian age." †

The shells in the green clay from Bore No. 1 and Bore No. 2 were remarkably well-preserved. Foraminifera were abundant, but whole specimens of other forms were rare. Dr. Lee has prepared the following list of fossils from this deposit:—

Truncatulina praecineta (*Karrer*).

This is the predominant form, described from the Miocene of the Banat, and common in the Miocene and Pliocene of Italy. Recorded by Brady from the coral-reefs of the tropics, 15-255 fathoms. Not recorded from Britain.

Truncatulina *sp.*

Rotalia Soldani d'Orb. Oligocene-Recent, cosmopolitan species.

? *Cristellaria* *sp.*

Nonionina asterizans (*Ficht and Moll*); Tertiary—Recent, cosmopolitan.

Nonionina scapha (*Ficht and Moll*); Miocene—Recent.

Fragment of brachiopod.

Nuculana *sp.*

Gasteropod.

Glacially straited belemnite (found near the top of the clay in No. 2 Bore).

Dr. Lee remarks on this list that "the general assemblage is decidedly post-Cretaceous in aspect, but differs in many respects from that found in the shelly boulder-clay of Caithness. For instance, the

* R. G. Carruthers, *loc. cit.*

† "Summary of Progress for 1908," *Mem. Geol. Surv.*, 1909, p. 75.

commonest form at Leavad, *Truncatulina praecincta*, has not been recorded at all from the Caithness boulder-clay. Its occurrence in the Italian Tertiaries and the coral-reefs of the Pacific, suggests that the Leavad clay may belong to some part of the Crag."

The borings have proved the Leavad transported mass of sandstone to be about 240 yds. long, 150 yds. broad, and 26 ft. thick. The underlying green clay extends at least 120 yds. farther to the north, and at one spot was found to be $25\frac{1}{2}$ ft. thick. No similar rocks are known *in situ* in Caithness, and as the direction of ice-movement was from the south or south-east, this huge erratic must have travelled from a locality now covered by the sea somewhere off Lybster or Dunbeath. On the lowest possible estimate it must be nine or ten miles distant from its original source.

J. S. F.

CHAPTER XIII.

RECENT DEPOSITS.

PEAT.

THE most evident and widespread recent deposit in Caithness is peat. Almost two-thirds of the surface of the county are still cloaked by it, and at one time it must have claimed a much wider area, since it has long been gradually receding before the spread of cultivation. The

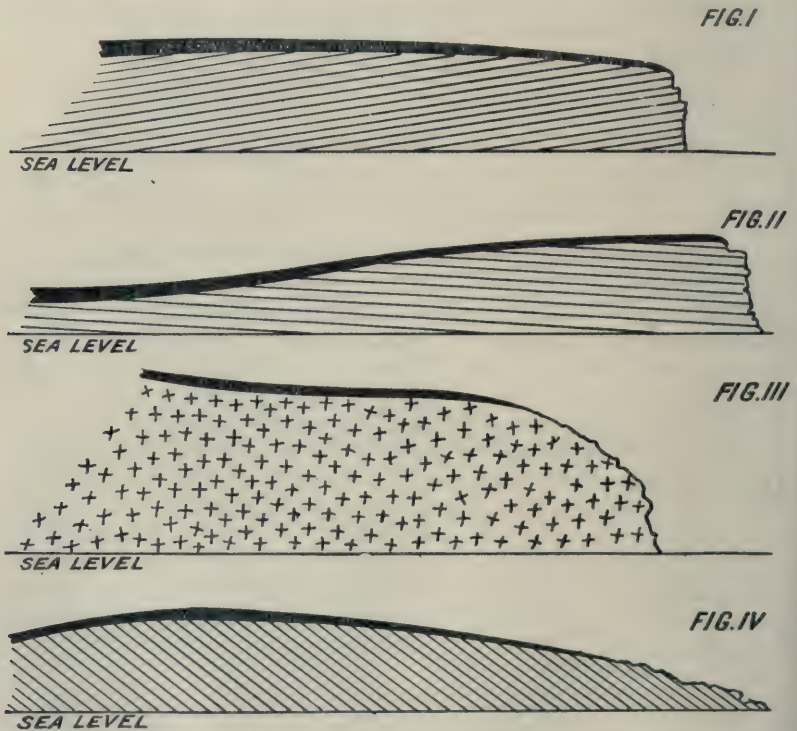


FIG. 26.—Diagrams to show the influence of the Coastal Profile on the Approach of Peat to the Coast-line.

numerous abrupt, artificial boundaries between the peat and the cultivated ground show how rapidly peat disappears when reclaimed by the plough. Large areas of partly denuded and wasting peat also margin the cultivated regions, and are due to spade-digging for fuel in places where renewed growth was rendered impossible by the improved condition of drainage.

Over nearly the whole of the interior of the county, peat forms an almost unbroken cover, and in many places is still of great thickness. There can be little doubt that before the era of cultivation, peat covered the whole county, except those places where from the steepness of the ground, or other causes, its growth was impossible. Thus it may have always been absent from some of the mountain plateaux such as Scaraben, on account of the great wind exposure and the porosity of the mantle of debris; also from the screes and piles of blocks which flank their sides. Other flat-topped high hills, as Beinn nam Bad Mòr, are, however, still covered with thick peat, and this is as generally the case with the rounded hill-tops of the Langwell forest as with the high level plateau or the plain of Caithness.

The approach of peat to the coast depends chiefly on the slope of the ground forming the coastal profile above the cliff. Thus where the ground backing the cliffs is flat, or gently sloping (Fig. 26, i and ii), peat comes close to the edge, as in places south of Inver Hill near Berriedale, near Ires Goe, between Freswick and Duncansby Head, and west of Reay. Sometimes the peat is thick right to the cliff-edge, as near Skirsa Head, and the exposure in section proves a comparatively recent advance of the sea. Evidence of this is both seen in the stacks near Clythshore (Plate III.) and Dunbar's Stack near Girston, which still have remnants of peat capping them, and must have been separated from the mainland since its formation.

Peat has been replaced by a coastal belt of cultivation, wherever the ground admitted of its being profitably established (Fig. 26, iv). Untilled but denuded patches included in the cultivated belt usually display a white clay leached of its iron compounds by a former covering of peat.

Where the coast profile is steep as near the Ord, at Inver Hill, between Dunbeath and Latheron, at Bruan, etc. (Fig. 26, iii), the slopes have never had a peat covering, and the dry soil has generally a reddish-brown colour from oxidised iron compounds.

The drainage system has a profound influence on the distribution of the peat and its vegetative covering. In the interior of the county, where decayed granite and sandy drift deposits underlie the peat, drainage channels are gradually formed by erosion at the junction of the peat and underlying debris, and an extensive underground system of drainage is developed. Far out on the high plateau the feeders of the Berriedale and Thurso rivers receive their waters from covered ways beneath the peat. The roofs of these covered ways or pipes collapse irregularly to form rows of sink holes. The bridges between these sink holes after a time fall in, and the feeders become more and more exposed to the light of day. The underground channels often get blocked by peat mud and blocks of fallen peat, or closed up by the movements induced by gravity in the peat covering. Such sinks and underground pipes are absent where peat overlies the stiff shelly boulder-clay, and movements in the peat can then only be induced by the slope of the ground or supersaturation of the peat or a combination of both factors. Polished slickensided surfaces may sometimes be seen separating layers of the peat or between the peat and the underlying drift. The slickensiding is orientated in the direction of the slope of the ground. Vertical cracks are also produced by settling or sliding of the peat. On the

south face of Beinn nam Bad Mòr the peat is gradually moving out of the corrie down the mountain slope like a glacier. On the Knockfin Heights there are numerous "dubh lochans" or "peat-holes" in the thick peat which masks the water-shed. They probably number several thousands, and others are scattered in small groups in various parts of Caithness. Two types of these "dubh lochans" occur :— (1) those typically met with on the plain of Caithness, and chiefly within the area occupied by the stiff shelly boulder-clay, and (2) those which occur in the peat with sinks, and where the underground system of drainage is prevalent. In all cases these "dubh lochans" have no relation to ordinary lakes in origin, since they invariably occur on the highest part of the divides between the various branches of the drainage system.

From a study of a great number of these lochans in Caithness and the neighbouring parts of Sutherland, the conclusion arrived at is that they can only be due to movements in the peat which disturb the surface and the drainage.*

Thick peat occurs from a height of over 1500 ft. in the Langwell Forest to near sea-level at the Loch of Wester.

In the Keiss Links peat is found beneath the blown sand. The following sections can be seen near and in a small drain which breaks through the sand-dunes about 200 yds. east of the new golf club-house :—

						Ft.
Sand	..	..	..	..	..	6+
Peat	..	..	..	..	..	3
Boulder-clay	..	..	..	..	..	4

The peat is here about 15 ft. above high-water mark, and about 15 ft. below a "kitchen midden" full of shells and bones, which in turn is covered by 6 ft. of blown sand. The peat contains birch sticks and fragments of plants which have been determined by F. J. Lewis, as *Phragmites communis*.

Peat also occurs under the sand in the neighbouring parts of Sinclair's Bay below low-water mark. This submarine peat is reported by the local fishermen to be full of tree stumps, and similar buried forests have been found below sea-level in Lybster Bay, Wick Bay, Thurso Bay, and in Skail Bay in the Orkneys. In his paper "On the submerged forests of Caithness," read before the British Association in 1859, Mr. John Cleghorn concluded that these submarine peats were laid down beneath the sea from material carried seaward by the burns.

Similar submarine peats and buried forests are found all round our coasts, and in several cases there is good evidence that the trees grew in the position in which their stumps are now found.

The available facts point to the submerged forest beds having been formed from trees which grew at a time when the sea-level was considerably lower than now, and during a drier climatic phase accompanying less insular geographical conditions. After a time the climate became wetter and more insular in character. With the sea's advance, the forest decayed and gave way to peat mosses,

* C. B. Crampton, "The Vegetation of Caithness considered in Relation to the Geology," 1911.

which became covered at first with blown sand, and eventually by the sea, which reached its maximum level about 5 ft. above the present high-water mark. At this time the site of Keiss Links must therefore have been occupied by extensive fresh-water and brackish marshes and lagoons in which the peat with *Phragmites* and fragments of wood was formed.

Since that time the sea has retreated and the climate appears to have become drier, since the peat mosses which greatly flourished and everywhere overlie the upper buried forest underwent decay. The Burn of Wester also obtained a somewhat greater seaward fall, and the drained marshes were covered with the drifting sand on which the prehistoric folk accumulated their kitchen middens.

During recent times the climate has probably again deteriorated, and the sea has advanced slowly on the land forcing the coastal sand-dunes in Sinclair's Bay to retreat gradually landwards. The outer margin of the sand-dune is often attacked by the sea during storms, the waves eroding large rugged hollows which the drifting sand is constantly attempting to obliterate.

The kind of trees in the Caithness submerged forests is not clearly stated in Mr. Cleghorn's report, but the submerged forest in the Bay of Skail on the west coast of the Mainland of the Orkneys, is stated by its discoverer, Mr. Watt, to consist * of fir trees (Scots fir) with their roots still attached. From this it is probable that the trees forming these submerged forests grew at the same time as those forming the upper buried forest in the peat bogs of Caithness which also consists of Scots fir. Firs are unknown from the lower buried forest in the north of Scotland.

Many natural sections and turbaries in the peat have been examined during the survey of Caithness. In a number of places where the basal layers of the peat can be observed resting on clay, the first growth appears to have consisted of dwarf willows which, according to Mr. Lewis, mark a bed formed under subarctic conditions. † This bed is generally followed in upward succession by remains of birch and locally of hazel. The birch layer usually forms the base of the peat when the subarctic bed is absent. Its wide distribution at or near the base of the peat in Caithness points to the peat-forming plants having been restricted at first to the most swampy places, and having become more widely spread on the death of the woodland scrub, but in some localities layers of birch are found through the lower three or four feet of the peat, proving that the birch scrub locally gained possession of the ground again and again after moorland conditions were general in the county. Nearer the surface of the peat in the central regions of the county, a buried forest of fir stumps is found over an area extending as far east as Hempriggs and south to Lochan Thulachan and Camster. This buried pine forest is best developed in the region of Forsinard and westwards into the head of Strath Ullie and the low-lying regions in the centre of Sutherland, and on Ben Griam Beg extends as high as the 1000-ft. contour. The only pines at the present time in Caithness are planted trees.

* *Edin. Phil. Journ.*, vol. iii., 1820, p. 100.

† "Plant Remains in the Scottish Peat-Mosses," pt. ii., *Trans. Roy. Soc. Edin.*, vol. xlv., 1906.

Further evidence supporting the view that Caithness has comparatively lately undergone a change in climate adverse to the rapid formation of peat and to its stability as regards erosion, will be found in the writer's *Vegetation of Caithness considered in Relation to the Geology*, to which the reader may be referred.

BLOWN SAND.

In the wide shallower bays at Keiss, Freswick, Dunnet, and Reay, there are extensive stretches of blown sand. In Thurso Bay sand gathers periodically between tide marks and is blown over the storm beach beneath the cliffs of boulder-clay which back the bay. Small quantities of sand also accumulate on ledges formed by landslips of the cliff, but no dune-formation is possible. When high seas arise with a gale from the north-east, the cliff of boulder-clay is attacked and the shingle may, in a few hours, be swept bare of the sand which has buried it for weeks.

Two types of blown sand accumulation are to be noted in these bays. At Dunnet Bay and Sinclair's Bay the sand forms a long almost unbroken range of dunes immediately above high-water mark, backed by extensive sand flats or links.

At Reay and Freswick, while a coastal dune follows the shore line, the dunes are much more irregularly distributed and extend farther inland. This difference in the distribution and extent of the sand-dunes is due to the difference in the nature and inclination of the surfaces on to which the sand is blown. Streams enter the sea in all these bays, but those at Reay and Freswick are rapid and have therefore cut well-defined channels which prevent wide flooding. The sand also overlies beach deposits and is free to move under the influence of the wind. The irregularity in the distribution of the dunes is due to irregularities in the growth of vegetation, sand fixation, and renewed excavation by the wind. At Dunnet Bay and Sinclair's Bay wide areas to the rear of the coastal range of sand-dunes lie almost at sea-level, and the sluggish streams have been forced by the great accumulation of sand to migrate from one point to another in order to breach the coastal dune. In former times, owing to their gentle gradient, they flooded wide areas to the rear of the coastal dunes, and temporary lagoons were formed which arrested the landward growth of dunes. The sand covering the flats is nowhere deep and overlies impermeable beds of peat and clay. Water therefore accumulates in the lower layers of sand, and owing to the want of slope may rise to the surface in wet weather and flood considerable areas.

A sandy strand faces Sinclair's Bay from a short distance north of Ackergill Tower to Rough of Stain, a distance of about three miles. To the north and south of these points shore reefs occur backed by small developments of the 5-ft. beach beneath low cliffs of boulder-clay. On the raised beaches minor accumulations of sand occur as a flat, thin covering, but the material is largely derived from shells which inhabit the shore reefs and after death are driven shorewards to form a beach, the finer comminuted debris being blown inland.

Quantities of shells are driven ashore and lodge behind the shore

reefs between John o' Groat's and the Bay of Sannick. They are chiefly deeper water, rock and *Laminaria*-dwelling, species, including *Modiola modiola*, *Buccinum undatum*, *Emarginula*, *Trinia europea*, *Pectunculus glycymeris*, *Capulus hungaricus*, *Helcion pellucidum*, and others, with numberless plates of a large barnacle. *Patella vulgata* is, however, abundant and derived from the shore reefs. A great accumulation of these shells in a comminuted condition backs the shore for the whole distance, and also extends inland for about 100 yds. as a thick deposit probably in part of the nature of a raised beach.

The surface of the deposit is chiefly fixed by vegetation, but has evidently been subject at a former time to wind drift. The material is much coarser than the quartzose sand of the other links and from its calcareous nature tends to consolidate gradually under the action of percolating water.

The great mass of broken shells backing the present beach is undoubtedly the accumulation of a very long period, and was probably formed during the retreat of the sea from the 5-ft. raised beach, but it now suffers erosion during storms, which points to a late advance of the sea on the land. Large accumulations of broken shells, such as those at John o' Groat's, point to an offshore rocky bottom kept clear of sediment by strong currents or wave action. Small quantities of shell sand accumulate behind shore reefs at Ackergill, Keiss and elsewhere, but the materials in these cases consists chiefly of fragments of shallow-water rock-dwellers, as *Littorina* and *Patella*, or sand-living lamellibranchs as *Tellina* and *Macra* from the sandy bottom beyond the reefs.

Great quantities of fine white quartzose sand have accumulated in many of the lochs in the interior of the county. Patches of blown sand are formed near the points of entrance of the burns where sand deltas are periodically exposed to the wind. The best examples of such deposits are seen at Lochs More, Shurrery, Caluim, and Tuim Ghlais. These lochs lie within the area of gravelly and sandy drift from which the sand is evidently derived by washing.

SEA BEACHES.

Sea beaches are absent beneath the flagstone cliffs except in some of the goes where there are trifling accumulations. The flagstone cliffs mostly descend into fairly deep water and are slowly attacked along joints and crushes. The flattened shape of fragments derived from them by erosion allows of the goes being swept clear by the undertow as fast as they are formed. Even such enormous excavations as Wife Goe, north of Skirsa Head (Plate IV.), which have very restricted seaward communications, accumulate little debris and are swept by the sea at all states of the tide.

Sea-cliffs of boulder-clay only occupy somewhat sheltered positions as in Thurso Bay, Gills Bay, and at the mouth of the Dunbeath Water. Beaches not only accumulate beneath these boulder-clay cliffs but also where boulder-clay reaches high-water mark in exposed positions somewhat protected by shore reefs of rock. Under the sea's attack the boulder-clay yields large quantities of boulders and stones to form a beach.

Sea beaches are also found beneath cliffs of the massive sandstones

of the John o' Groat's Group south of Duncansby Head, and those of the Upper Old Red Sandstone of Dunnet Head, in all but the most exposed parts of the headland. The sandstone is dislodged in great blocks, which accumulate beneath and gradually become rounded into huge boulders. Owing probably to the late retreat of the sea from the higher level of the 5-ft. beach, many of these boulder beaches are now dead and lichen-covered. Large landslips of the cliff, as at the Tràigh Bhuidhe (yellow beach), the Tràigh Fhada (long beach) near Berriedale, and the Tràigh Loisgte (beach of the burning), south of Dunbeath, have also given rise to beaches. In these the local supply of debris has either been too great or of too ponderous a nature for the waves to rapidly disperse. In the first case the landslip consists of enormous blocks of the Badbea Breccia which resist removal even better than the sandstone boulders already referred to.

RAISED BEACHES AND DESERTED PLATFORMS.

One of the most remarkable features about the geology of Caithness is the absence of any indication of the 100-ft. raised beach which is represented elsewhere on the Scottish coasts. This raised beach was formed during a period of submergence in late glacial or early post-glacial times. Its absence in Caithness cannot be accounted for by subsequent marine erosion since the 100-ft. contour extends far inland in parts of the county. Depression of the land might account for its absence, but it is well-developed at Helmsdale immediately south of the Ord, and high-level beaches are also indicated on the north coast of Sutherland. The land depression would therefore be limited to the Old Red Sandstone areas north and east of the crystalline rocks of Sutherland. There are facts which suggest that Caithness has lately undergone differential depression relative to sea-level.

No 50-ft. raised beach is found in Caithness, but a lower raised beach varying from 8 to 5 ft. above the sea is found in suitable localities from a point north of the Ord all round the Caithness coast. On the coast of Sutherland, south of the Ord, there are well-preserved beaches at the 100-ft., 50-ft., and 15-ft. levels, the last being largely covered by blown sand. The 15-ft. raised beach of Brora may be the same as the Caithness raised beach which is 8 ft. above sea-level near Dunglas and at Dunbeath, but only 5 ft. farther north at Ackergill, Keiss, and Freswick and various places on the north coast. At Papigoe and Nybster it is matched by a rock notch and platform at the same level.

Apart from theories of differential depression of the land the only feasible hypothesis is that Caithness was still partly covered by ice while the higher beaches were forming along other parts of the coastline.

The available evidence is strongly against land-derived glaciers being the cause of the absence of the higher raised beaches. It is conceivable, however, that during early post-glacial times a great mass of dead ice, a remnant of the great continental ice-sheet which filled the North Sea in glacial times, persisted as a covering to parts of Caithness and the islands to the north, and excluded the sea from a large area of the sea-bottom near the edge of the continental platform in the North Sea.

RIVER ALLUVIA.

The materials forming the river alluvia in Caithness vary from gravels to loams. Nearly the whole is derived from the drift, since river sections involving recent rapid erosion of solid rocks are scarce.

Along the Langwell and Berriedale Waters the alluvia consist of sand or rounded gravels from the erosion and washing of the sandy drift. They are usually thin and lie on platforms eroded in the sandy boulder-clay.

Numerous terraces of this nature occur to a great height above the present river channels, and demonstrate clearly the directions pursued by the rivers in their former courses and the extent of erosion of the drift. The Langwell and Berriedale Rivers rise and fall very rapidly, and all the silt derived from the drift is carried out to sea.

The alluvia of the Dunbeath Water differ greatly from those of the Langwell and Berriedale Waters. In its middle course the river has excavated chasms in the flagstones, and the drift it traverses for long distances contains numerous slabs of these rocks. The alluvia of the lower reaches of the river display in consequence quantities of these flagstone slabs imbedded in a sandy and gravelly loam. The alluvia are thicker and less rapidly permeable than those of the Langwell and Berriedale Waters and support a more luxuriant vegetation.

The alluvial haughs of the lower Wick and Thurso Rivers are still liable to flooding in spite of artificial restrictions, and formerly must have supported extensive marshes. They consist of fine brown loams of some thickness chiefly derived from erosion of the boulder-clay but with admixture of humus. In a few places where the boulder-clay beneath the loam is undergoing erosion, local deposits of sand and gravel occur in the river beds. This shows that the loam is formed by silts which have been carried considerable distances by the river before being laid down on the flood plain.

C. B. C.

CHAPTER XIV.

PHYSICAL FEATURES OF CAITHNESS.

IN Caithness, as elsewhere, the factors underlying the topography are statical and dynamical; the differential resistance to disintegration and decay, and the structure and distribution of the rock masses on the one hand, and on the other the localisation of forces leading to erosion, translation, and deposition. But an evolutionary origin is everywhere evident, and the apparently stable surface relief is a compound of relics of many past changes. Simple as the topography of Caithness may at first appear, many of its features are the result of agents which have long since ceased to work, while a few in their incipience date back to the remote past of the Old Red Sandstone period.

On entering Caithness for the first time by the railway route, the great expanse of slightly undulating moorland may disappoint a traveller accustomed to the hills and valleys of the Scottish Highlands. Once on the coast, this feeling is changed for interest and satisfaction, as the rocks are disclosed in cliffs of novel aspect. The fantastic outlines of the stacks and goes immediately arrest the attention, expressing clearly and simultaneously the relentless nature of the sea's attack, and the inequality in the land's defence.

Following the coast, one is astonished at the many thousand feet of strata so sharply delineated in the cliffs, which form an endless succession of pictures of structure and erosion, geologically simple it may be, but vivid in their strength. The Caithness cliffs are to be numbered among those wonderlands which delight the eye of the artist and other lovers of nature, such as the geologist, ornithologist and botanist. In time too, one is sure to yield to the fascination of that wide moorland expanse, which conjures up the lowland prospect of Neolithic man in a way that none of the more cultivated tracts can do.

The description of the physical features will be taken in the following order :—

- I. The Caithness plain and plateau ; its probable origin.
- II. The effect of glaciation on the topography.
- III. Post-glacial erosion.
- IV. The statical factors in the evolution of the topography.

I. THE CAITHNESS PLAIN AND PLATEAU ; ITS PROBABLE ORIGIN.

Caithness may be described as a plain somewhat raised above sea-level and dissected into gentle contours by the agencies of erosion. Along the county march, between the Ord and Forsinard, it rises to a plateau, with a greatest elevation of 1200 ft., but gradually declines

in a northerly direction, and more rapidly to the north-east, until, in the region about Sinclair's Bay, a considerable area of the land is barely 50 ft. above sea-level. But this slope is by no means a regular and continuous one, as may be seen by reference to contoured maps. From the Knockfin Heights, the name given to the central part of the high plateau on the county march, the main watershed extends, as an unbroken barrier, in an easterly direction through Ben Alisky and Caplaich Hill to Stemster Hill, and separates the head-waters of the northward flowing Thurso River from those of the Berriedale and Dunbeath Waters, which flow to the south-east.

From Stemster Hill a watershed continues eastward to the coast at Sarclet, but the main divide turns due north across lower ground, and extends through Spital Hill to the Hill of Odrig, parting the Wick and Thurso Rivers. From the Hill of Odrig, the watershed continues east-north-east with an ill-defined course to Duncansby Head. It is, in places, not much more than 100 ft. above sea-level, and some of the streams link in the peaty flats.

From the irregular and intricate nature of the water-partings in Caithness, in absence of signs of recent complex movements of the crust, it is obvious that the drainage system has at some past period attained maturity, and that the so-called Caithness plain is not of recent origin. Many parts of the pre-glacial water-courses, however, ran in gorges beneath the general level of the plateau, consequent on periods of rejuvenescence of the drainage by upheaval in pre-glacial times, while the present system of gorges is due to erosion following a remoulding of the plateau surface by glaciation.

The Old Red Sandstone of Caithness has been thrown into a number of folds. There is conflicting evidence as to the time at which these flexures of the crust took place.

That some occurred previous to the laying down of the unconformable Upper Old Red strata in Hoy in the Orkney Islands is, however, certain. The Brough upthrust-fault, along with numerous other north-and-south dislocations, must have resulted from tangential movements of the crust, such as have led to the minor north-and-south flexures, and have indeed been found along their strike to die out in these folds. The Brough fault truncates the Upper Old Red Sandstone of Dunnet Head, and must therefore have been moving at a date posterior to the deposition of these strata. On the east coast of Sutherland, farther to the south, faults with a similar trend have affected the Mesozoic strata.

It therefore appears that the dislocations of the Caithness Old Red Sandstone rocks began at an early date, and have probably continued at intervals into Tertiary times.

The present river-courses traverse the flexures, and therefore either came into existence previous to their formation, or began their work of erosion on the surface of later geological strata, by which these folds were buried. In the latter case, the river-courses would in all probability be post-Mesozoic in origin.

The history of the evolution of the Caithness plain in its earlier stages is obscure. On its later stages the history of the present drainage system sheds some light.

Inspection of contoured maps shows that a broken belt of higher ground passes from the north-west part of Caithness along the whole

length of the western side of the Orkney Islands. The belt is now, for the most part, broken up into "monadnocks," some of which are isolated by the sea, but the whole must at one time have been continuous with the higher ground which forms the 1200-ft. plateau of the border lands of Caithness and Sutherland. The latter probably extended not only much farther into Sutherland, but also had a wide extension to the north-west and north-east, and sloped in these directions. High above this plateau stand up, in grim isolation, Morven, Scaraben, Maiden Pap, and some lesser heights of the Langwell forest-country, and beyond the confines of the county the two Ben Griams, Ben Armine, and other solitary hills, bear equal evidence of an early period of erosion, during which this plateau was formed by removal of great masses of rock from above its present surface. These mountain masses alone escaped the processes of erosion, and now stand out boldly with little or no apparent relation to the present drainage system.

It is difficult to determine if this erosion was performed at a much earlier epoch of geological history or by the pre-glacial forerunners of the present drainage system; but these, either before or after the isolation of the higher mountain masses, became engrafted on the country as two groups, one flowing in an easterly and south-easterly direction, and the other in a northerly and north-westerly one, away from the axis still marked out by the ridge of high ground which extends from Caithness into the Orkney Islands.

The head-waters of these two river systems, namely, the Langwell, Berriedale, Dunbeath, and Wick rivers and the Latheronwheel, Reisgill, and Clyth burns, still approximately follow their original courses. The head-waters of the northerly flowing streams gradually invaded the country, in an irregular manner, farther to the south and east, and, beheading the feeders of the easterly flowing rivers, have left in their wake "monadnocks," many of which have doubtless disappeared, but others remain marking the positions of the deserted watersheds of the stolen country. Such "monadnocks" are seen in the Hill of Forss at Holborn Head and Dunnet Head, which in remote times formed part of the water-parting extending to Hoy in the Orkney Islands. Since that time the water-parting has been forced back to pass from the Hill of Olig to Warth Hill and Duncansby Head. Further, from a study of the submarine contours, previous to the time the Pentland Firth was entered by the sea, the water-parting must have crossed to South Ronaldshay and swept round the mainland of Orkney, north of Scapa Flow, only again to join the ancient watershed at Hoy by this very circuitous route.

The eastern rivers belong, in all probability, to the easterly flowing system of the Scottish Highlands, which are generally considered to date back to the Miocene or late Eocene. The northerly-flowing streams can also be compared with the later westerly-flowing streams of the Highlands, the agents of erosion of the now sunken fiords of the west coast of Scotland.

Although the time and the original agent of sculpture of Morven and the other Old Red Sandstone "monadnocks" is not certainly known, it is otherwise as regards the slopes of Scaraben, and some of the lesser hills of crystalline quartzite of the Langwell forest.

Here the conglomerates, of Old Red Sandstone age, creep up the slopes from base to summit. Moreover, conglomerates of local derivation occupy the bed of the Berriedale Water at the northern end of the deep gorge by which the river traverses the quartzite outcrop, and even enter to some extent the deep gaps in the quartzite mountain farther to the west. In fact, there can be little doubt that the Scaraben ridge was carved out, in the rough, near the beginning of the Orcadian Old Red history, and was gradually enveloped and buried in the accumulating sediments of the period. Its reappearance as a mountain in the present scenery, a relic of a former period of erosion, was doubtless synchronous with the carving out of Morven.

II. THE EFFECT OF GLACIATION ON THE TOPOGRAPHY.

Generally speaking the effect of glaciation on Caithness was to mask the previously existing topography. The old river channels, in places deeply eroded in rock, with almost vertical walls, were choked with boulder-clay, which was further left as thick sheets, filling gentle hollows, and swathing prominences. The east and north coasts of Caithness were bevelled by the passage of the ice. Where the coast profile was abrupt the higher part of the slope suffered erosion, while the lower part was swathed in boulder-clay, and narrow gullies in the slope were packed with the same material. Where the profile was gentle its slopes were rendered more uniform by a mantle of boulder-clay of varying thickness.

The features of the interior were charged by an impressed new topography, gentle, it is true, but appreciable in the field, and marked by orientation in relation to the direction of ice-flow. This to some extent can be studied in the lines of contour on the Ordnance maps of the district, which exhibit this general tendency to parallelism in conformity with local movements of the ice. It is most marked in the low country of the north-east of Caithness where the numerous small hollows and prominences have an elongation parallel with the direction of ice-movement due to a simultaneous erosion of rock and swathing with boulder-clay.

This type of topography is, however, confined to those parts of Caithness over which the shelly boulder-clay was dragged from sea to sea, and is replaced in the south and west of the county by one in which the hills alone bear testimony of passing ice, and where the lower ground is scattered with irregular mounds and lines of moraines, marking the retreat of a radiating valley glaciation.

Along the south-east coast, between Lybster and Sarclet, the great sheet of ice, in its north-north-westerly advance, had to surmount the water-parting, extending from Stemster Hill to Sarclet. Between Clyth and Ulbster, where the seaward incline is steepest; and also where the submarine contours approach the shore most closely, great resistance must have been encountered by the ice passing inland from the basin of the North Sea, which resulted in deep scoring of the rock-surface. Moreover, the strike of the rocks and numerous north and south lines of crush conformed in the main to the direction of movement of the ice.

From this a peculiar topography has evolved consisting of

innumerable ridges and hollows, following the harder and softer bands in the rocks. The ice, moving northward, mounted the cliffs obliquely, producing a terraced slope by removal of material from the softer bands of rock. This terraced slope has been in most places subsequently destroyed by sea erosion and replaced by cliffs. Locally, however, it still remains as a series of scarps, with ledges dipping gently landward, descending almost to sea-level. In the higher part of the terraced slope the grooves are still filled by boulder-clay, but the latter has been removed as far up as the sea has been able to reach. Nearer the present watershed, this peculiar topography reaches its acme of development in the Warehouse district, where deep ice-worn grooves and ridges have been further accentuated by the action of flowing water, held up along a retreating ice-barrier, and forming a deeply scarred and channelled ground, which in Caithness is unique. A narrow col on the watershed at Upper Camster probably owes its present depth and width to the ice which became constricted in it in its passage over the water-parting.

The relatively smooth gentle slopes, which stretch far away to the north, speak for the release afforded to the ice, which, on surmounting the barrier, ceased to erode the rock, and spread out its *moraine profonde* as a gently rolling sheet upon the surface. This slope of boulder-clay extends as far as the Wick River and Loch Watten, and forms, except where it has been cultivated, a wide peat-covered, almost featureless, expanse.

Spital Hill, Warth Hill, and the Hill of Olig, like the other smaller elevations of the lower-lying districts, have smooth rounded contours, but stand up in the gently rolling landscape, their summits planed by the ice, their flanks swathed with boulder-clay, so that at a distance they appear as whale-backed elevations in the gently undulating moorland.

Farther to the south and west, the higher hills of Ben-a-chielt and Ben Dorrery have bold but smooth outlines, and elongated shapes that conform in a remarkable degree with the local direction of ice-movement. The structure of the former hill is such that it might be expected to have somewhat this elongated shape and orientation. This, however, is not the case with Ben Dorrery, where the strike of the rocks is across the length of the ridge, and there seems reason for thinking that its shape may in some measure be due to glaciation.

A further feature of Ben Dorrery is the lines of moraine, which simulate ancient shore lines along its western flank. Beinn Ràtha and Beinn nam Bad Mòr are ringed with such moraines, and Ben Alisky shows them on its northern flank. These features are not seen on the hills farther to the east, and are characteristic of the "nunataks" and bounding ridges of the shrinking ice. Of the high "monadnocks" of the plateau country, the majestic truncated cone of Morven, and the lesser Maiden Pap, afford excellent instances of the effects of over-steepening of the flanks by glacial action. This alone has resulted in the enormous block-screes in which all but the tops of these mountains are buried.

The north-westerly elongation so frequent in the lakes of Caithness is due to glaciation. In most cases the lakes occupy hollows in the drift, but some, like Loch Sarclet, are true rock-basins.

The river systems were greatly modified by the redistribution of surface material by the ice, but no marked change was effected in their main courses.

All the larger streams, in some part of their courses, follow pre-glacial channels; but different parts of the same rivers attained their present channels under the influence of different topographic factors, and the more important will be taken separately for exemplification.

Between Wick and Watten the Wick River has a general east-south-east direction. But alternate segments, with a south-east or north-east trend, together constitute a somewhat zigzag course, and these, according to their orientation, differ in their topography. The longer south-east segments occupy shallow hollows longer than the river segments, whose direction of flow they have evidently determined. Wide stretches of alluvium flank the sluggish streams in these segments.

The lower part of the Burn of Haster, and the Burn of Winless, enter the Wick River in exactly opposite directions at either end of the south-easterly orientated segment between them, and form with it a straight line following a glacial groove in the boulder-clay.

The shorter north-easterly segments have followed the shortest and lowest routes around the intervening boulder-clay ridges. The north-easterly segment at the Braes of Gillock has cut a deep trench in the boulder-clay.

The only other branches of the Wick River below Watten follow glacial hollows. The Tarroul Burn flows south-east, and the burn draining the Loch of Hempriggs north-west; the latter entering the Wick River at Janetstown against the flow of the main stream.

The larger branches of the Wick River, the Achairn Burn, the Strath Burn, and the Burn of Acharole, began their work on the surface of the great boulder-clay slope that stretches southward from the Wick River. Their general northerly trend is due to the pre-glacial slope of the ground, but in their twists and turns and more or less parallel segments, they have been manifestly directed by the later impressed glacial topography. Those segments and branches, which conform in their orientation to this topography, are for the most part sluggish, and have done little or no work of excavation. The cross-segments, on the other hand, are more rapidly corradig, frequently expose the rock, and are sometimes accompanied by high alluvial terraces, good examples of which occur along the course of the Strath Burn.

Only the main course of the Wick River below Watten can be considered with any certainty to be following a pre-glacial course. This is, however, completely buried in the drift. The channel near the mouth of the river is known to be of considerable depth.

Over a great part of its lower course the Thurso River also is flowing over the site of its pre-glacial channel, which, like that of the Wick River, is deeply buried in boulder-clay.

The present zigzag course of the river is due to the glacially impressed topography. The north-westerly segment, between Hoy and Todholes, occupies an extensive alluvial flat in a glacially impressed hollow, which, continuing farther north-west towards Janetstown, is occupied by a small branch stream, flowing in a south-easterly direction, *i.e.* contrary to the flow in the main river.

At Todholes the river enters a gorge in the boulder-clay, which, for a mile below, has plugged the pre-glacial channel to a great depth. The rectangular bends of the river, between Halkirk and Olgrinmore, have resulted from the alternating predominant influences of the impressed glacial topography, with north-north-west ridges and hollows, and the original north and north-easterly slope of the ground. The long north-west stretch, between Olgrinmore and Dalemore, follows, in all probability, a line of crush in the rocks, which is further the *prima causa* of the remarkably straight line forming the east shore of Loch Calder and the Forss Water, for the last four miles before it enters the sea. There is, however, little doubt that this line has been in part accentuated by the ice, and in part swathed and masked by boulder-clay, and the Thurso River, in its present course, between Dale and Olgrinmore, is flowing on the boulder-clay lying in a groove of the rock. The Forss Water, in the direction of its numerous rectangular bends, repeats, in a striking manner, but on a lesser scale, the configuration of the Thurso River. Examination of this district shows that the direction of glaciation almost coincides with the strike of the rocks, and that these factors have shared in producing the topography which has influenced the course of the river.

Above Dalemore, the Thurso River, free from the directing influence of the glacial ridges and hollows, follows a general north-easterly course in the wide gravelly and moraine-strewn hollow, formerly occupied by the Strathmore glacier.

Turning next to the rivers south of the watershed which extends from the Knockfin Heights to Sarelet, we find that, in accord with their shorter courses, their descent seaward is more rapid. The great depth of post-glacial erosion in their lower courses is, however, dependent on their having reopened their pre-glacial channels, and is chiefly at the expense of the boulder-clay which filled them at one time to below present sea-level. The Langwell and the Berriedale Waters, encircling the mountains of the Langwell forest, enter the sea by a common mouth at Berriedale. They receive most of their waters from the water-logged peat covering the plateau along the county march. The relations of the Langwell to the old pre-glacial gorge are best displayed in its last mile, where it traverses the sandstone flags of the Berriedale Group. The pre-glacial gorge in this part of its course was originally steeper-sided than in the crystalline rocks higher up the river. Further, the ice travelled down the Langwell Water towards the coast and widened the original valley, but, at some distance above its mouth, was deflected, to pass in a direction parallel with the coast-line and so traversed this part of the old gorge of the river from south to north. The latter part of the old channel was therefore packed with boulder-clay and preserved from widening by ice erosion.

The Berriedale Water, for the last two miles above its mouth, also has a south-easterly trend, almost at right angles to the local direction of ice-movement, but, above this, it takes an abrupt turn to the north-north-east, along a line which probably nearly coincided with the easterly margin of the seaward-going ice.

The phenomena met with in these two segments of the Langwell and Berriedale Waters differ considerably.

In the lower parts of the Langwell and Berriedale Waters rocky

slopes or cliffs follow the northern banks, while the south sides are formed by steep banks or slipping cliffs of boulder-clay. The northern walls of the pre-glacial gorges are thus often well exposed, but the southern walls are, for the most part, still hidden by boulder-clay.

Judging by the height and closeness of approach of rock behind the boulder-clay on the south side of the Langwell gorge, the southern wall of the old river channel must locally have been very steep, or even precipitous. The sections here given (Fig. 27) will further demonstrate this point.

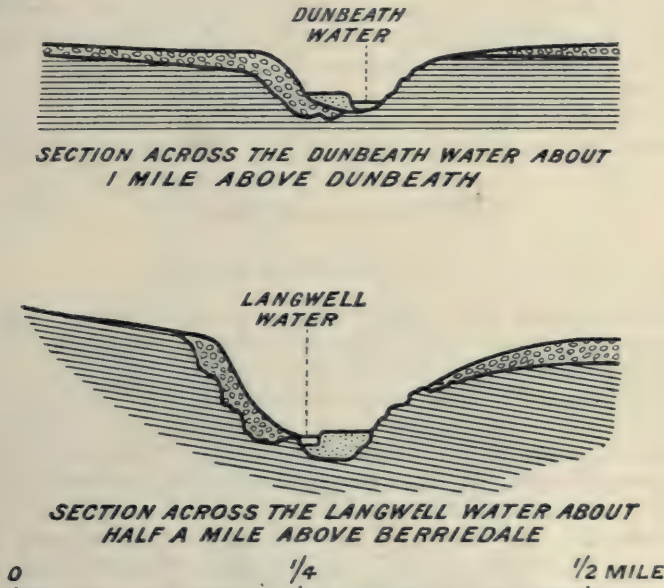


FIG. 27.—Sections across the Dunbeath Water and the Langwell Water, to illustrate Post-glacial Erosion in Pre-glacial Rock Gorges.

Further up these rivers have no longer laid bare the rocky wall only along one bank, but are cutting into drift, or exposing rock, at various places on either flank. That they even here occupy the sites of pre-glacial channels is evident, since they lie in deep trenches in the rocky plateau, from which they have as yet failed to remove all the drift. Their channels are flanked by a succession of terraces, eroded in the boulder-clay. At Altnabea the valley of the Langwell Water rapidly widens out, and a short distance farther up the river is cutting across moraines, occupying the floor of the valley. On the Berriedale Water the same phase is reached only near Braemore, six miles from the sea. Gravelly mounds of a morainic nature are also found lower down the valleys; on the Langwell to below Braigh na h-Eaglaise, and on the Berriedale to nearly as far as An Dùn; but these mounds in all cases lie far above the present level of the rivers, and are separated from them by terraces cut in the drift. From this, it seems probable that a considerable amount of erosion took place during the retreat of the valley glaciers that laid down these moraines.

For two miles above its mouth, as far as Balantrath, the Dunbeath Water almost recapitulates the phenomena met with in the lowest reaches of the Langwell and Berriedale Waters. But the lower part

of the Dunbeath Water and its branches lies within the area of the shelly boulder-clay, and the direction of ice-movement was very constantly to the north-west, only locally conforming with the direction of the old channel. This has to some extent induced a glacially impressed topography such as has been described in the case of the Wick and Thurso Rivers, and has influenced the direction of drainage. The north-west segments of the Dunbeath Water between Dunbeath and the mouth of the Houstry Burn, that between Balantrath and Loedebest, the Allt Bhualteach above Achorn, and the Allt an Learanaich, all follow wider channels, partly of glacial impression, but in some cases extensively deepened, with an accompanying formation of terraces of erosion in the boulder-clay. The east-and-west segment of the river above the mouth of the Houstry Burn, the lower part of the Achorn Burn, and the segment above Loedebest, lay across the direction of ice-movement and now exhibit narrower gorge-like channels.

III. POST-GLACIAL EROSION.

1. *Post-glacial Rock Gorges.*

Where the rivers have failed to discover the old pre-glacial channels, new deep rock gorges have been cut, the best examples of which are found in the Reisgill and Clyth Burns near the sea, and in the branches and the main channel of the Dunbeath Water farther inland.

The Reisgill rock gorge (Fig. 28) is over half a mile in length. The burn leaves the pre-glacial channel about 200 yds. below the main road, and only regains it near the harbour, before entering the Bay of Lybster.

Also between the main road and the sea is the rock gorge of the Clyth Burn (Fig. 29), which plunges down several waterfalls and finally leaps about 80 ft. over the cliff into the sea. The lower part of the pre-glacial channel, choked with boulder-clay, is seen on the coast near Ceann Hilligoe, half a mile farther to the south. It occupies a line of fault, which, farther inland, is followed by the present stream. There are several post-glacial gorges on the Dunbeath Water and its branches. None in Caithness is finer than that on the Achorn Burn, a narrow chasm in the flagstones, headed by a waterfall. Equally instructive is the gorge on the main stream, about one-third of a mile above Balantrath.

2. *Marine Erosion.*

Boulder-clay may have swathed extensive stretches of the present coast-line when the ice first retreated from Caithness. The existing seaward profile must have been continued to below the present sea-level. If the ice continued to occupy the basin of the North Sea after the land was bare, much of the boulder-clay may have been removed by waters running between the ice and the high features which occupied the site of the existing cliffs, but the latter have doubtless been largely exposed and have assumed their present condition by removal of the lower part of the seaward slope by marine erosion. Where the seaward profile was gentle, and especially where the ice had passed seawards from the land, as along the north coast, the rock would be margined by smooth slopes of boulder-clay; but in all cases the boulder-clay has been removed by the sea up to a

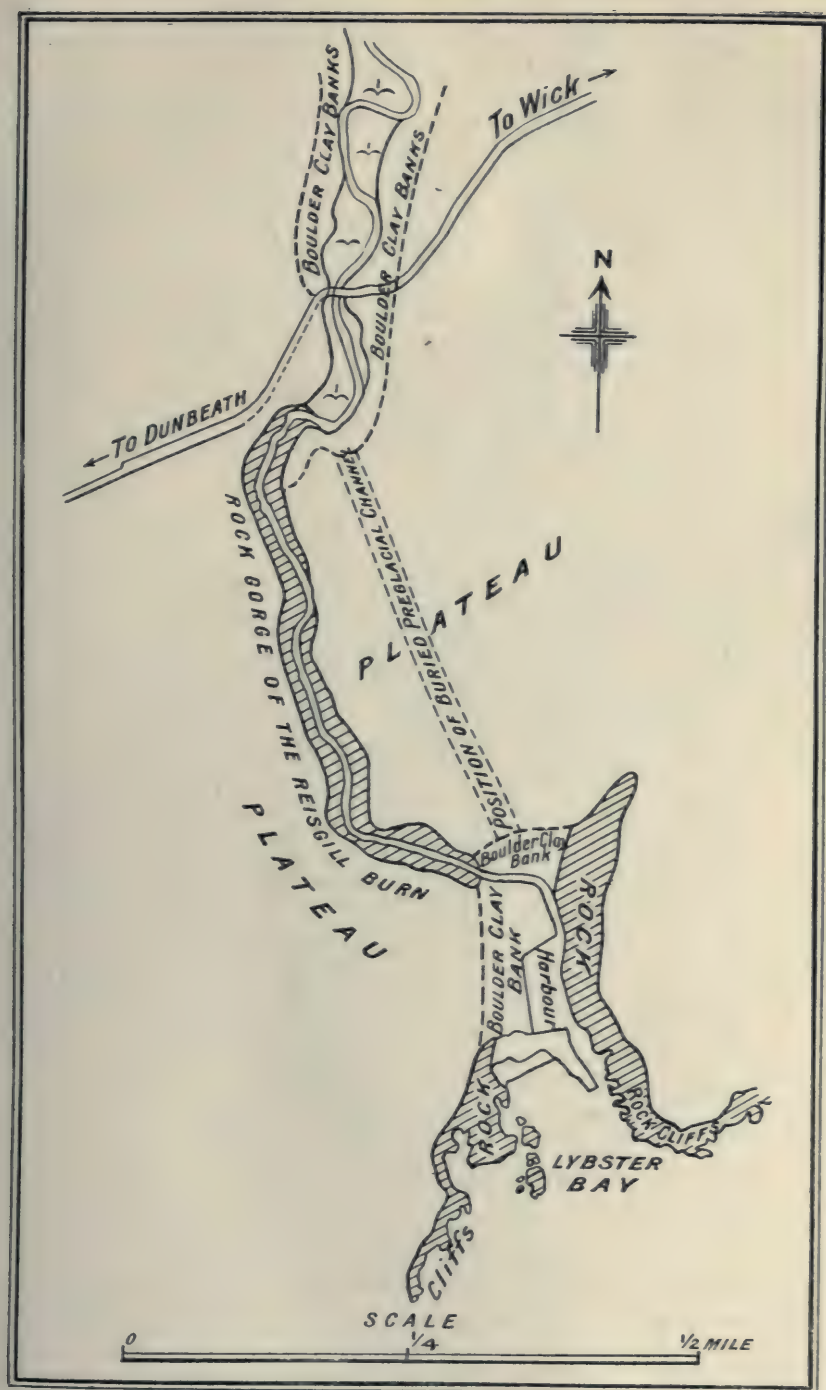


FIG. 28.—Map illustrating the Relation of the Rock Gorges of the Reigill Burn to the Buried Pre-glacial Channel.

level where rock was encountered in the belt of marine erosion between tide marks (Fig. 30). Where the rock formed a steep face behind the boulder-clay the former has been laid bare and has undergone

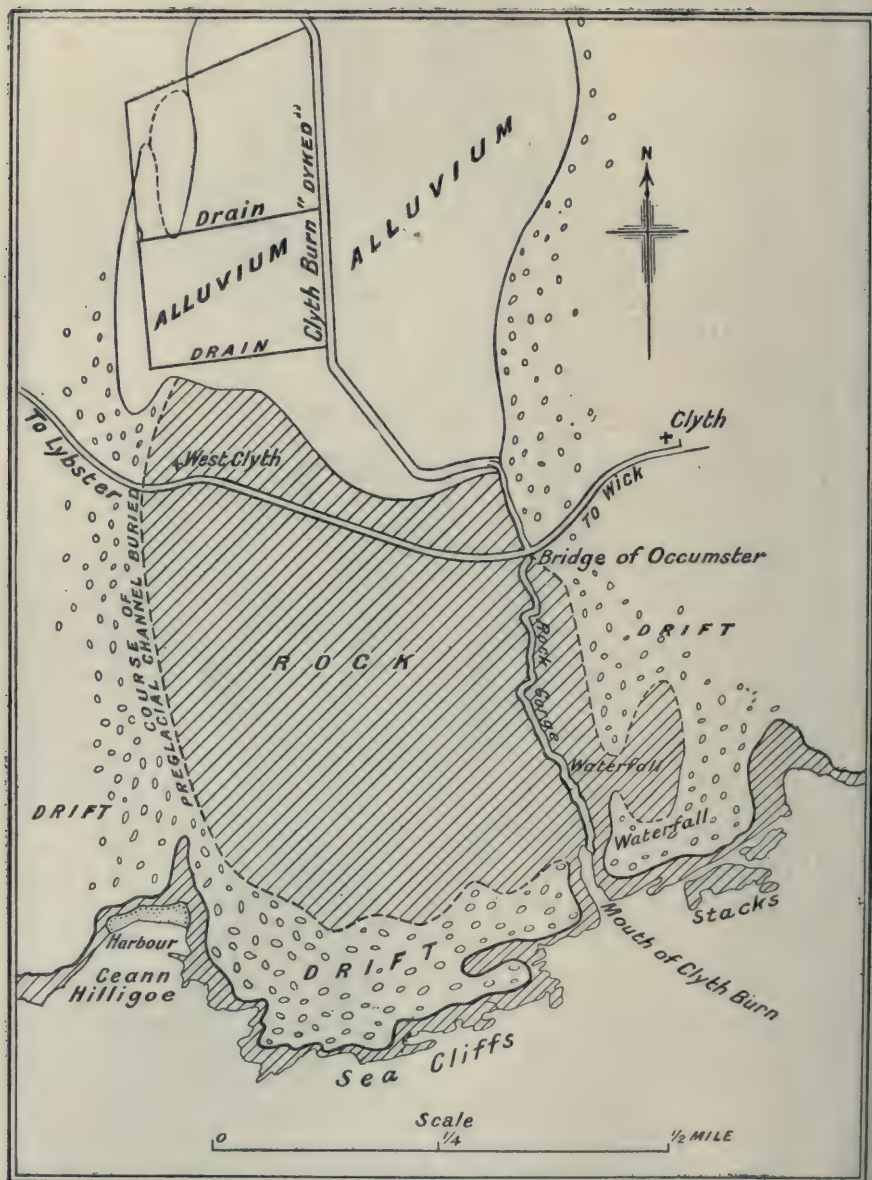


FIG. 29.—Map illustrating the Relation of the Rock Gorge of the Clyth Burn to the Buried Pre-glacial Channel.

further marine erosion to form the existing cliffs (see line of erosion, No. 2, in Fig. 30). In some places boulder-clay occupies hollows in the rocks, extending below the present sea-level. The sea entering these hollows has generally removed the boulder-clay until it has

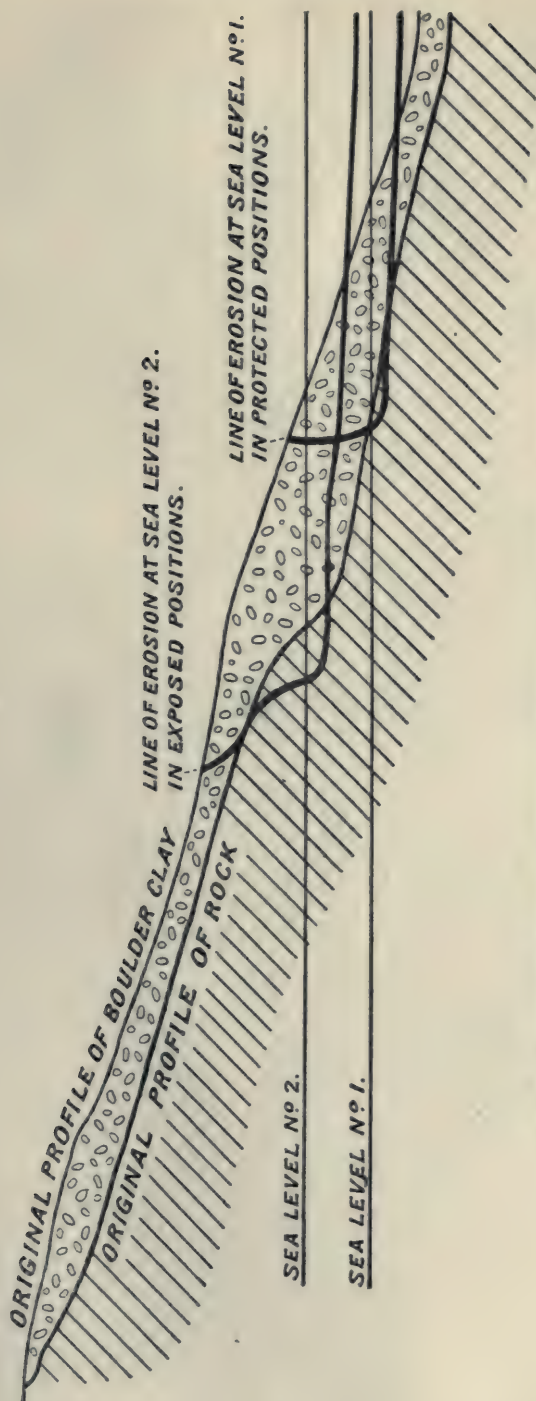


FIG. 30.—Diagram to show Relations between Glaciated Coastal Profiles and Marine Erosion.

met a check to its progress either by encountering rock between tide-marks, as in Gills Bay and other smaller inlets backed by cliffs of boulder-clay (see line of erosion No. 1 in Fig. 30), or by the accumulation of sand shallowing the waters and decreasing the reach of the waves as in the broader bays of Sinclair and Dunnet. In the latter both causes have been operative, the extent of marine erosion in their outer parts being limited by reefs, while the central segment tends to have the outline of a perfect arc defined by the conflict between sand accumulation and wave erosion.

Boulder-clay cliffs face the sea in Thurso Bay, Gills Bay, and at Dunbeath. They are protected by reefs between tide-marks but are still subject to erosion during storms. Apart from exposure the rapidity of this erosion depends on the degree of protection afforded by the reefs. In Thurso Bay the soft rocks forming the reefs have suffered much erosion, and are only exposed at low tide. The boulder-clay cliff is fronted by a storm beach of shingle derived from the stones in the boulder-clay. The storm beach acts as a protection to the cliff at high water, but forms an efficient battery for its further erosion during storms.

The amount of marine erosion experienced by the rock cliffs since the glacial period is very difficult to determine. One point is, however, clear, viz., that the sea has never risen higher on the land during this period than a few feet at most above the present high-water mark. Besides the boulder-clay cliffs in the bays mentioned above, drift is still found backing many "goes" and sticking to their walls in positions where it would have been removed had the sea ever advanced much farther on the land. Boulder-clay also forms a thick capping to low rock cliffs in many places, and has only been removed so far as might be expected by a slight elevation of the sea-level above its present one. In many of the goes or along the cliff-tops where the boulder-clay has been eroded by the sea, it is now dressed with vegetation to an extent pointing to a slight retreat of the sea from a higher level, such as can be matched by the evidence of raised beaches and rock platforms discussed in the last chapter.

In this connection the well-known accumulation of boulders called the "greystones" south of Wick is of peculiar interest. These large slabs of sandstone cumbering the cliff-top have been derived from the rock *in situ* in the immediate vicinity. A careful examination shows that many of these blocks, some weighing many hundred-weights, have been moved by the force of the waves during storms. They are heaped together and lie overlapping, inclined towards the direction of the sea's attack. Caithness geologists* have not only carefully recorded these facts, but have further stated their belief that the stones have been quarried from the top of the cliff by the force of the waves. Some of these blocks measure 7 to 8 ft. square, and are 2 to 3 ft. thick, and there is good reason for thinking they have been loosened and moved in the first instance by ice. One of the largest of these blocks has only been displaced a short distance upwards and outwards from its sandstone bed at the verge of the

* Mr. Johnston of Wick has reported on "the greystones" at length in articles in the Wick papers, and they have also been the subject of much discussion by Mr. Johnston, Mr. Simpson, and members of the Caithness Field Club.

cliff, and is resting on rounded stones, a fact to which my attention was drawn by Mr. Simpson of Wick. These can be seen from the cavity on one side of the block locally called "Charlie's Cave." It would be difficult to explain how these rounded stones were inserted beneath the block by the waves. A more probable explanation is found by appealing to the influence of ice. At this part of the cliff the strike of the beds is at right angles to the direction taken by the ice, clearly shown by well-defined striae on the cliff-top about 100 yds. distant. The beds dip in the direction of the ice-movement and must have opposed their prominent basset-edges to its pressure. Blocks of the sandstone dislodged by the ice can be followed as a train still half-buried in the drift farther from the edge of the cliff. The block at "Charlie's Cave" was therefore in all probability lifted by the ice partly from its bed and packed beneath by drift. When the sea began to wash the cliff-top during storms, the drift was removed with the exception of some of the included stones which remained supporting the block. The other "greystones" were doubtless also originally lifted from their bed by ice. They have, however, undoubtedly been moved and rearranged by wave action, but their surfaces are thickly covered with lichens, and from this it would appear that the sea has of late ceased to influence them to any extent. Their present arrangement probably took place when the sea stood at a higher level, when the raised beaches and platforms were formed.

There is evidence to show that the land has stood higher relatively to sea-level than at the present time. The near approach everywhere of deep water to the cliffs suggests that the land has undergone depression in post-glacial times, and the submerged forests at different parts of the Caithness coast-line afford evidence in the same direction.

There is a deep channel filled with sand and mud in the Wick River above the harbour mouth. According to Mr. Simpson, the Wick town authorities had much difficulty in obtaining foundations in the bed of the river when the town stone bridge was being constructed. "All along its site no bottom was found at 70 ft., and the bridge had to be founded on piles. Large water-logged boats have sunk out of sight in the bed of the river lower down. The bed of the river is 3 to 4 ft. below high-water mark at these points. Bottom was not found at 50 ft. near the Service Bridge and the Lower Weir, where the bed of the river is 6 ft. below high water." These points would be from 4 to 6 ft. above low water at Wick Harbour. Shell marl was obtained from beneath the mud in Wick Harbour some years ago, but, unfortunately, no specimens are now available for examination. The presence of this marl, if verified, would point to a loch along that part of the river course now submerged by the sea. From these data it seems clear that the Wick River at some time since the glacial period has eroded its channel to a depth of at least 60 ft. below present low water, and the sea-level must, of course, have been considerably lower than this.

3. Post-glacial Rock Disintegration of the Mountain Plateaux.

Owing to disintegration by frost glacial striae are absent on the higher mountain-tops. The top of Morven is almost covered by gravel

derived from the weathering of the conglomerate, while its flanks are buried in blocks of enormous dimensions.

The quartzite of Scaraben is hidden by a thick mantle of frost debris. The frost debris is almost as marked a feature of the higher mountain plateaux of Caithness as of the Northern Highlands. The quartzite hills are not only more uniformly buried in angular debris and scree, but the debris-covered surfaces descend to much lower elevations than is usual on hills of other rocks. So much is this the case that it is often difficult to find any solid rock *in situ* on the hills formed of quartzite. The rock is unaffected by the chemical agents of decay, and no clay is formed through its disintegration, with the result that all the water falling on the surface of the highly angular, porous debris is immediately carried below and no surface erosion by running water can take place. The water which filters through the debris comes to the surface as springs on the lower slopes of the hills.

The debris generally consists of larger fragments near the rock exposures and at the highest points of the summits crowning the ridges, and becomes progressively finer towards the rounded shoulders overlooking the flanks of the hills. On these shoulders the debris is frequently spread as a series of step-like terraces at slightly different elevations, each margined by an abrupt almost vertical face running parallel with the contours, and from a few inches to a foot or more in height. These terraces are apparently due to irregularity in the downward creep of the debris under the influence of gravity, and the presence of coarser debris on the summits of the ridges is thus probably to be explained by the rock having been more recently exposed in these positions.

Excavations made on the summit of Scaraben, for the purpose of fixing the deer fence, showed a layer of fine white silt beneath the debris. This is probably formed from the fine particles of quartzite carried down by percolating water, and layers of this material may act locally as gliding planes between the debris and the rock. The creep of the debris is possibly also induced by freezing and thawing of water in the lower layers. It is probable that the accumulation was due to the early emergence of these higher mountain tops from the *mer de glace* causing pronounced frost-disintegration of rock. The debris could not be removed owing to the want of sufficient slope and the highly porous nature of the material. There is a shallow, sink-like hollow containing peat in the quartzite debris covering one of the lower saddles separating the summits of the Scaraben ridge. This may point to the plateau debris at some former period having been peat-covered in the more protected places. The hollow is perhaps due to the rapid vertical descent of water along a crack in the former peat covering. A number of mountain tops in the neighbouring parts of Sutherland, formed of other rocks, but quite as high and exposed as Scaraben, are almost entirely peat-covered, and it is evident that the porosity of the quartzite debris is inimical to the growth of peat or to its preservation from destruction when once formed. The relations between the plateau debris and the vegetation are discussed in the writer's *Vegetation of Caithness considered in Relation to the Geology*.

4. The Influence of Peat Growth on the Topography.

Where the peat is very thick in the interior of the county, it has completely buried all minor surface features due to glaciation. The growth of peat has, however, had a general preservative influence on the topography from its power of retarding the flow of water precipitated on its surface. Much of this is held in the sponge-like growth and much is evaporated, the only streams capable of erosion being those with sufficient force and volume to prevent the growth of *Sphagnum* and other moorland plants. During periods of great peat-growth, the work of erosion in the head-waters of the river systems was limited to the fewest possible tributaries, but in these the volume of water was kept more constant with a smaller rise and fall than it would have been otherwise. In regions where a system of drainage has developed beneath the peat, the rise and fall of the tributary head-waters may, however, be very rapid, and erosion proceeds at a much greater rate.

It has already been shown that the peat at one time reached the cliff top along extensive stretches of the coast-line. The more diffuse seaward drainage resulting from such a distribution of the peat mosses must have caused more rapid weathering along the joints and crushes in the rocks near the cliff edge preparatory to the sea's attack. The sea's advance on the land would, therefore, be increased along stretches of the coast where the growth of peat occurred.

IV. THE INFLUENCE OF STATICAL FACTORS ON THE EVOLUTION OF THE SCENERY.

Leaving the more dynamical aspect of the evolution of the topography, we may turn to study shortly the statistical factors. These chiefly depend on differences in the reaction of the various types of rocks to decay and erosion.

With these are included the effects of faults, crushings, and tiltings of the rocks, since their results largely depend on the stage at which they were induced.

The Effect of the Nature of the Rocks on the Evolution of the Inland Scenery.

The granite and granitised gneisses which form most of the uplands tend under favourable conditions to decay deeply and rather regularly, and have therefore yielded, under repeated periods of weathering and erosion culminating in glaciation, the smooth flowing outlines characteristic of the high plateau and such rounded hills as Braigh na h-Eaglaise which form its dissected remnants.

The peculiar topography of the diorite country near Reay, where the numerous rounded knobs of diorite form so characteristic a scenery, is due to much irregularity in a more selective but otherwise similar process of deep decay followed by glaciation.

More resistant than the associated crystalline rocks, the quartzite betrays the strike of its folds by mountain ridges. Slow to decay, it disintegrates superficially by the action of frost, all projecting points breaking down to add to the angular debris that buries its

tops and covers its slopes with screes. Its smooth though bold profiles are thus preserved from destruction.

All the prominent hills rising above the high plateau, those of quartzite excepted, consist of outliers of the Old Red Sandstone formed either entirely of conglomerate or of sandstones and mudstones capped by conglomerate. Morven and Maiden Pap, the most typical of these mountains, have cone-shaped outlines, which are due to the formation of screes of enormous blocks following on the over-steepening of their flanks by glacial erosion. These conglomerate hills have a strange, isolated, "butte" like character, the origin of which is an interesting problem. They are remnants of a sheet of conglomerate, the greater part of which has disappeared through denudation.

Conglomerates are particularly apt to give rise to chasms and cliffs. This appears to be partly due to the porosity of the gravels into which their deeply-weathered surfaces are resolved. This limits erosion to powerful water currents capable of moving gravels and shingles, all but large streams sinking beneath the surface. Such powerful currents find tools ready made in the pebbles, and rapid vertical cutting results in the chasms so characteristic of streams traversing conglomerates. The preliminary process in the formation of these hills, no doubt, consisted in the rapid cutting of chasms in a plateau underlain by a sheet of conglomerate. When the streams entered the softer beds beneath, lateral erosion would be greater, but from its unfrequent joint-planes the conglomerate only falls in large blocks and so would continue to form steep or vertical faces. As dissection of the plateau proceeded, the conglomerate formed a protection to each mass of higher ground, but the "butte" shaped relics show that the dissection was carried to extremes, comparable with the results of the erosion of a large river system traversing an arid region, which in such cases are intensified by its almost complete limitation to the water-courses. There are, unfortunately, no data to prove the date of the base levelling of the high plateau of Caithness, and the conditions of erosion suggested might point to the Triassic, late Jurassic, or some period during Tertiary times.

The Effect of the Nature of the Rocks on the Evolution of the Coast Scenery.

The Caithness coast extends with frequent changes in the type of scenery for about 100 miles from the Ord to beyond Reay. On a small-scale map it appears with a smooth but slightly angular profile, interrupted by only a few headlands or indentations, which are more-over blunt in their outlines. Any one judging distances by measurements on the map, and intending to follow the cliff-verge, finds, however, that the coast is often rendered minutely irregular by an extraordinary number of inlets called "goes."

The slopes overlooking the granite cliffs of the Ord, or where massive sandstones or conglomerates face the sea, are very steep, and the walking difficult. In the flagstone area of Caithness, a walk along the cliffs is much delayed by the goes mentioned above, as the cliffs are only absent for $3\frac{1}{2}$ miles in Sinclair's Bay, for $2\frac{1}{2}$ miles in Dunnet Bay, and for short distances in Freswick Bay, Sandside Bay, and at John o' Groat's, and at all these places the strand is backed by stretches of blown sand.

The highest cliffs are south of Berriedale, where in several places granite forms almost vertical faces as much as 400 ft. in height.

Sandstone cliffs, about 300 ft. in height, occur south of Berriedale, between Berriedale and Dunbeath, and at Dunnet Head. Sandstone cliffs also rise to over 200 ft. near the stacks of Duncansby.

The highest flagstone cliffs, 200 ft. or more, are those west of Thurso and south of Wick.

Speaking generally, the submarine contours approach the Caithness coast where the land is high, and recede where it is low. This, so far as the bays and promontaries are concerned, is probably to be chiefly accounted for by the distribution of sediment on the sea-bottom in reference to currents.

There is, however, a tendency for the submarine contours to specially close in towards the coast at points where the highest land contours locally approach the top of the cliff, *e.g.* where the top of the high cliff is a plateau, which declines inland. This is seen at Duncansby Head, Dunnet Head, and Holborn Head. These high points are the summits of hills which have been cut back by the sea to their water-partings.

Granite, conglomerate, sandstones, and flagstones (Plates I., II., III., IV., V.) form different types of cliff scenery in Caithness. The high granite cliffs between the Ord and the mouth of the Ousdale Burn are irregularly-jointed, but the larger joints are inclined at high angles to the horizon, and the cliffs are therefore rugged with massive buttresses. The conglomerate cliffs between Sarclet and the Stack of Ulbster (Plate II.) are so massive as to present at a distance the appearance of granite. The sea works up great vertical joints forming caves and columnar buttresses, but the retreat of the cliff is slow as the intervening blocks resist removal. The caves advance great distances like mines, but the conglomerate stands out as a headland beyond the neighbouring softer cliffs of mudstone.

The high cliffs of John o' Groat's Sandstone, south of Duncansby Head, and the Upper Old Red Sandstone cliffs of Dunnet Head, are similar in lithology and scenery. These somewhat calcareous sandstones are far softer than the flagstones and lack their impervious cement-like character.

Besides vertical master joints, there are other joint planes which slope at high angles to the horizon. The recesses in these sandstone cliffs are therefore frequently of a broken funnel shape, the wide entrance at the cliff top sloping steeply down into deep water.

"Goe" like inlets in the sandstone cliffs of Dunnet Head are due to erosion along decomposed dykes of igneous rock.

South of Duncansby Head the high vertical cliff of the John o' Groat's Sandstone overlooks a narrow platform of marine erosion. As if to mark its former greater height, it has left as relics on the platform the magnificent pyramidal stacks of Duncansby (Plate I.), one of which, more than 200 ft. in height, overtops the cliff and forms with its summit a projection of the land surface rising seawards. Comparison of that part of the coast-line between Thirle Door and Fast Goe and those parts to the north and south, shows that the middle section has retreated, and yet the cliff is higher. The middle section formed by the sandstone cliff is faced by the platform of retreat, while the pro-

jecting flagstone cliffs to the north and south pass directly down into deeper water.

The platform is narrow and evidently of comparatively recent origin, as it rapidly gives place to deeper water beyond. It was probably chiefly formed during the advance of the sea to form the 5-ft. raised beach, as the base of the cliff is now protected by a narrow beach of lichen-covered boulders.

The more rapid erosion of the sandstone cliffs, compared with those of flagstone, may be partly due to the large size of the sandstone blocks which form effective tools for the assault of the base of the cliff.

Excepting the freestones of Dunnet Head and John o' Groat's, and the basement red sandstones and mudstones, the Old Red Sandstone rocks are remarkably alike in their reaction to the agents of erosion and decay, though in colour and composition they vary much from band to band. It is, moreover, on these properties that their peculiar differences from other rocks depend. Their hardness, toughness, and fissile, laminated character constitute them flagstones, while their fineness of grain and the complete filling of the minutest pores with lime render them practically air- and water-tight.

The limitation of decay to exposed surfaces and easy removal of the weathered crust are the main peculiarities in their weathering, but the different laminae are unequally affected, and some stand out as narrow ledges on a weathered cliff, while others retreat (Plate V, 2), giving a picturesque character to the scenery.

The cemented nature of the rocks causes them to react in bulk to tensile forces, and vertical joint planes are of great depth and form the chief structural lines of weakness. The faults are also usually vertical or nearly so, and the crushes and characteristic "rucks" (Plate V, 2) are limited by vertical parallel joint planes, between which the rocks are brecciated or upturned at various angles.

These vertical planes form the only channels through which water can easily percolate the rock masses. The joint planes cross one another in the direction of the dip and strike of the strata, and map out the flagstones into blocks of a more or less rectangular shape. The joints in unweathered rocks are sealed by calcite, but act as the weakest planes to the attack of organic acids when exposed at the surface. Large blocks thus outlined by decay are dislodged by the action of frost or by undermining through erosion. The joints are widely spaced except near lines of disturbance, and large rectangular sections of the rocks may long outlive the more jointed or disturbed rocks in the vicinity.

The planes of bedding, though so well marked, are, except in disturbed areas, hermetically sealed against percolating waters. The finely laminated character tends, however, to make the rocks fissile, and fresh blocks may be dislodged by undermining. When in a horizontal position and little jointed, the flagstones are almost unassailable and their strength is frequently demonstrated by the natural tables, bridges, and arches which ornament the coast.

A long pre-glacial seaward slope is usually accompanied by low cliffs; an absence of a seaward slope or an abrupt one is accompanied by high cliffs.

A strike of the rocks nearly parallel with the coast-line and a steep

dip lead to shore reefs. A strike at right angles to the coast-line and a steep dip accompany skerries, and the coast is then dangerous to shipping.

The grandest cliffs are found where the land is high and the flags are lying horizontally or at very gentle angles. It is in such cliffs that the "goes" so characteristic of the Caithness flagstones are typically developed, and it is in relation to these cliffs that the well-known "cletts" or rectangular stacks appear (Plate III.).

The goes are for the most part worked out by the sea along lines of crush or along "rucks" where the beds are tilted between vertical joint planes. They are typically long inlets, with more or less parallel and vertical side walls, which rise to the full height of the cliff. When deep water penetrates to the far end of the goe it enters a cave at the base of the overhanging end wall. In many cases, however, at the end of a goe there is a beach backed by a slope of talus or drift. In the first case extension of the goe is in progress. In the latter, either retreat of the sea has occurred and the vertical end is covered by talus or the hollow is pre-glacial in origin and has not yet been entirely cleared of the boulder-clay with which it was plugged. Typical goes are practically confined to horizontal or gently dipping flagstone strata. The inlets in tilted rocks are far more irregular in nature. When crushes are numerous and very narrow, the sea often mines caves for great distances. The waves entering these caves act as a piston compressing the air in the cavity. On recoil of a wave the pressure is suddenly released and the alternate compression and expansion loosen the decayed material in the roof and end wall of the cave. This process of erosion may extend so far upwards that the roof of the cave at the end falls in and a "spout hole" is formed. "Spout holes" occur in the conglomerate at Sarclet and in the flagstones at Holborn Head, where the whole headland is undermined by caves.

At many places along the coast the land may be seen subsiding along narrow strips parallel with the edge of the cliff. The best instance occurs near Samuel's Goe, north of Nybster, where extensive undermining has occurred. In such places the process by which stacks are formed is made manifest, and the newly formed blocks may be compared with the stacks in the vicinity.

The endurance of the stacks in horizontally bedded flagstones is striking evidence of the strength of the cement-like blocks which form them. They are frequently as high as the cliff and often so narrow as to appear merely as pillars. Others are of great bulk, as the Clett at Holborn Head. As evidence that the lines of weakness which map out a stack are formed by the gentle processes of rotting and subsidence along joints and crushes, and that all active erosion takes place by undermining, the tops of many of the stacks have a capping of boulder-clay and in some cases even of peat. In time, however, these caps disappear before the erosion of wind and rain, and the stacks are attacked at all their joints by the fury of the waves. In this way some massive stacks like The Brough are undermined by caves and become in time table-like structures supported on legs. Smaller stacks are often reduced at the base till their massive tops are supported on a pillar which appears as if it would snap before the wind. Few stacks are seen at so great a distance as 100 yds. from

the cliff, but whether this distance marks a period of recent erosion or not, it is difficult to say. From the rapid falling of the submarine contours seawards, and other proofs of recent progressive subsidence, it is probable that stacks formed at a greater distance from the present cliff face would now be submerged even had they continued to stand against the onslaught of the sea.

C. B. C.

CHAPTER XV.

ECONOMIC GEOLOGY.

CAITHNESS FLAGSTONES.

THE regular free jointing, the finely laminated bedding, and the durable nature of the flagstones have for many centuries proved of great service to the inhabitants of Caithness. The pre-historic folk made free use of loose slabs in building, and probably to some extent quarried the stone, since they used comparatively large squared flags with which they sometimes ingeniously constructed doors to move on pivots of round stones on the cup and ball principle.

Since the advent of civilisation, scattered houses, many villages, and two large towns have been built entirely with rocks of local origin. In the towns and throughout the county the houses have been built, the roofs slated, the roads paved, the fields fenced, and the drains lined with Caithness flags, so varied are the uses to which the rocks are adapted.

The quarrying and shaping of flagstones for export has long been one of the chief Caithness industries, and pavement made of this durable stone may be seen in many of our cities, and flagstones have been exported from Caithness to distant countries.

The first quarry for exporting pavement was opened by a Mr. Scott in the neighbourhood of Murkle.* The Castlehill quarry was opened by Mr. Traill of Rattar in 1824, and the first shipment of flagstones occurred in 1825.† The industry steadily increased until shortly after the end of last century, but of late years has considerably diminished, as may be seen from the official statistics tabulated below. In the old Statistical Account of Scotland, published in 1845, it is stated that flags were being exported to London, Newcastle, Glasgow, and other towns. Two hundred and fifty men were employed in Thurso parish, and 100 labourers at Castlehill, where machinery was established for sawing and polishing the flags. Between 3000 and 4000 tons of flagstones were being exported from Castlehill alone at that time.

* For this information we are indebted to Mr. William Durrant, Provost of Thurso.

† See *Trans. of the Highland and Agricultural Society of Scotland*, vol. vii. p. 256.

The following statistics of production are taken from the official reports.*

	Tons.		
1856. Castlehill	7,000		
1858. Caithness	16,600	Value.	
1895. "	15,545	£18,206	Persons
1896. "	24,258	31,906	Employed.
1897. "	21,633	28,131	403
1898. "	17,818	22,484	404
1899. "	23,029	21,934	478
1900. "	18,794	17,378	454
1901. "	20,951	20,241	500
1902. "	34,804	23,239	414
1903. "	15,907	20,252	301
1904. "	18,187	20,404	402
1905. "	17,528	12,998	324†
1906. "	15,534	10,109	205†
1907. "	15,306	5,770	142†
1908. "	9,880	6,409	191†
1909. "	9,914	7,936	201
1910. "	7,400	5,605	154
1911. "	6,036	4,153	145

The decline in the industry during the last few years is probably connected with the extent to which concrete pavement has come to be used.

Grades of Stone Quarried.

The rocks may be classified according to their uses as follows :—

1. Rough flags or second quality flagstones.
2. First quality flagstones.
3. Stone slates.
4. Building stone.
5. Road metal.

1. Rough Flags.

These are obtainable in any part of the county where the Flagstone Series is at the surface. Small quarries have been opened in all the inhabited districts to obtain stones for various purposes. A second quality of flagstones from the quarries for first-class pavement flags is largely used for making fences.

2. First quality Flagstones.

These appear to have been quarried from two main horizons in the Thurso Flagstone Group. The higher horizon extends from near Castle-town in a westerly direction to Weydale and Whitemoss and again from the quarries at Holborn Head through Hill of Forss and Janetstown.

The lower horizon is quarried at Spital and Achscrabster, and is considered on the whole the more durable rock.

Owing to the rapid repetition of bands of rock which to the eye are exactly like those quarried, it is, however, impossible to say if actually the same band has been quarried at each of these horizons or

* "Mineral Statistics," *Mem. Geol. Surv.*, and "Reports on Mines and Quarries," *Home Office Reports*.

† For the years 1905 to 1908 the value and labour employed include the estimates for quarrying building stone (massive sandstone flag) noted in the returns under Igneous Rocks.

several bands lying within a few hundred feet of one another. The latter is the more probable. The rocks of Thurso Flagstone Group, explained in another chapter (p. 95), show rapid changes in character with constant repetitions of series of bands of rather different characters. The first quality flagstones usually form the most calcareous and least arenaceous layer in each sequence, and it would depend on the thickness of this layer and its composition whether it be workable to advantage or not. These layers may vary from a few inches to several feet in thickness. Their fitness for pavement depends on their perfectly smooth bedding planes and the facility with which the rock splits to the thickness required. Such a rock usually has widely spaced joints allowing large sizes of flags to be obtained of a regular shape. The durability of the flagstone probably depends on its fine-grained character and cement-like properties and on the nature of its constituent minerals. The chief flagstone quarries are as follows :—

Castlehill Quarries, near Castletown ; Birklehill Quarry and Stonegun Quarry—in Olrig Parish ; Weydale Quarries, Whitemoss Quarry, Janetstown Quarries, Holborn Head Quarry, and Hill of Forss Quarries—in Thurso Parish. Achscrabster Quarries in Halkirk Parish, Spital Quarries in the parishes of Halkirk and Watten.

The ports of shipment are Thurso, Scrabster, and formerly Castletown. The flags are shipped to many British and foreign ports.

Methods of Working Flagstones.—The flagstones quarries are driven as open workings from the outcrop. In certain cases, as at the Holborn Head Quarries (Plate VII, 1), where the dip is very gentle and the slope of the ground in the same direction, the working faces can be driven against the dip, and the floor of the quarry is kept dry by natural drainage. In other cases pumping has to be resorted to, but quarries in the Caithness flagstones are more troubled by surface than ground waters owing to the impervious nature of the rocks and the close and generally sealed nature of the joints.

The quarries are driven as far as the expense of removal of the “tiring” (the rock overlying the band specially suitable for pavement) will allow. No mining is resorted to, nor is blasting employed. The “tiring” is taken up layer by layer, by means of levers, until a sufficiently large surface of the flagstone pavement is exposed. The main joints in this layer are then opened by wedges and the pavement flags are lifted in layers of definite thickness by levers in the hands of experienced workmen. Each flag, as it is loosened from its bed, is taken away from the scene of operations by means of a crane and subjected to a preliminary squaring. As the working face advances in the large quarries that have been working for long periods, a perfectly smooth surface which formed the bed of the pavement layer is left as a floor to the quarry, and where the “tiring” is easily disposed of, as at Holborn Head, this floor in its unencumbered condition may be very extensive and forms a striking demonstration of the characteristic evenness of the bedding of the Caithness Flagstones.

The further shaping and finishing of the flagstones is sometimes done by hand, but cutting and polishing machinery has long been employed in Caithness. The chief flagstone works at present are situated at Thurso Harbour. There are also machines at the Spital Quarries, and formerly Castletown was the chief centre of these operations.

At the Thurso Flagstone Works (Plate VII, 2) the engine and main driving shaft, with gear and belting, are covered by a long central shed having on either side an open yard in which the cutting machines are arranged at regular intervals.

The flags are placed on long tables which can be wheeled beneath the cutting machines.

In each yard six connecting rods from the machinery move backwards and forwards, for a distance of about a foot, six heavy horizontal beams of the same length as the tables. Each beam carries two knives with plane edges, and is swung on large frame supports by two iron rods attached to chains, which work over pulleys with adjustable weights. The knives lie parallel on either side of the beam along its whole length, and, travelling with it, come in contact with the flags, one knife operating each table.

Two pairs of tables on wheels are supplied for each pair of knives, and, by means of cross-rails, each pair can alternately be brought beneath the knives, or drawn away, in order to have the flags that are cut removed and replaced by others. Thus the flag-cutting on one pair of tables, and on the other the removal of finished flags and adjustment of fresh flags, can be carried on at the same time.

A long sand trough with water pipes, attached to the supports on either side of the beam, continually feeds the knives with sand and water.

A row of flags to be cut is adjusted to position on each table by means of short wooden levers with projecting iron points, and fixed by wooden blocks and wedges, and the tables when wheeled under the knives are steadied by wooden props.

The cut is not carried completely through the flags, but after about one-half to three-quarters of an hour's cutting, according to the thickness of the stone, the machine is stopped and the tables drawn aside and replaced by others.

The flags are then trimmed by knocking off the edge of stone beyond the saw cut with a hammer from below. Sometimes the surface of the flags is polished. This is done under cover of a shed. The polishing tables move on wheels like those used for cutting, but are broader in proportion to their length, and have splashboards. The polish is obtained by means of flat concentric iron rings, slightly spaced in a horizontal plane, and given an excentric rotation by a vertical shaft. The polished flags are used for special inside work only, such as flooring of lobbies and granaries, hearthstones, table tops, and mantelpieces.

The usual stock sizes of the shaped flags are from 2 to 6 ft. in length, and 1 to 4 ft. in breadth, but much larger sizes can be supplied. Good examples of large flags may be seen at Scrabster where each of the four walls of the office of the Holborn Head Flagstone Quarries consists of a single large flag.

Flags of unusual length are sometimes obtained and are used for gateposts and even for posts for drying-greens.

The thicker flags are chiefly used for paving, the thinner for damp-courses in building.

3. *Stone Slates.*

True slates are not found in Caithness, but formerly certain qualities of thin flags were universally used as roofing material.



1. HOLBORN HEAD FLAGSTONE QUARRY.



2. FLAGSTONE CUTTING MACHINERY, THURSO.

A very hard, thin, dark, micaceous flag was specially quarried at Achanarras and elsewhere for the purpose. Unlike true slates Caithness "stone slates" will not bear "holing," and are therefore difficult to replace, and the working of this class of "slate" has been abandoned. A special type of pale green thin flag or "slate" has, however, been much in demand lately for artistic work on churches and public buildings, and is exported to England from Thurso. These thin flags are obtained at Whitemoss near the surface. A spade is used in levering up the "slates," and they are trimmed into shape by hand with the hammer against a straight edge.

4. Building Stone.

Rough building stone of fair quality is obtainable from the thicker beds of arenaceous flagstones throughout the county. The best building stone is quarried around Wick from the Wick Flagstone Group and from the large quarry at Scrabster. The rock is a very fine-grained sandstone with a calcareous matrix and is impermeable to water. It occurs in thin beds intercalated in the flagstones. It has a clean vertical jointing and requires but little shaping for building purposes. It is termed "whin" in Caithness, and appears in consequence amongst the igneous rocks in the Home Office returns for the county.

In the districts of Duncansby and Huna many of the houses are built of the yellow and red freestone of the John o' Groat's Sandstone Group. This is a somewhat porous, slightly calcareous freestone that is easily dressed and should work well under the chisel. It appears, however, to be less durable than the Wick stone. The Dunnet Head sandstone is similar in character and has also been used for building. Large blocks can be obtained, and the stone has been used for making gate-posts, rollers, millstones, etc.

ROAD METAL.

Probably the best material for road metal in Caithness could be procured from the monchiquite dykes. They are, however, scarce, and only two, at Reaster and Toftcarl respectively, appear to have been so used. The Wick "whin" is worked for road metal wherever it is handy and is of good quality. The sandstone bands in the Janetstown quarries and elsewhere between Thurso and Reay are also much in demand. The coarser dark flagstones of the Wick Group are also extensively used and are far superior for this purpose to the softer greenish flags of the Thurso Group. Between Freswick and John o' Groat's the roads are red from the use of the freestone, but their surface is inferior to those made of "whin." On the roads in the Langwell forest and between Strathmore and Glutt recourse has been had to breaking up the boulders of gneiss and granite in the mounds of drift, and on the road from Dunbeath to Braemore the gravel from decayed conglomerate has been employed. Granite and arkose are used for mending the Ord road south of Berriedale.

SAND AND GRAVEL.

There is an abundant supply of quartzose sand conveniently located

in the links of Dunnet, Keiss, Freswick, and Reay. There are also sandpits at Leavad, about half-way on the road between Latheron and Mybster. The Leavad sand is derived from the decay of a large ice-transported mass of sandstone of Cretaceous age. Being quite free from salt it is probably of better quality for building purposes than sand from the links. The sand used in the flag-cutting machines is obtained from Leavad and Dunnet. At Berriedale sand is obtained from the river terraces on the Langwell Water. In the centre of the county around Strathmore and northwards to Shurrery large quantities of white quartzose sand, due to washing of the drift deposits, are accumulating in the lakes. The granite under the moorland peat is often weathered deeply into a growan or felspathic sand, and near Altnabreac Station is dug in pits and distributed by rail. This sand and gravel has a fine reddish colour, and is used for garden walks and drives.

LIMESTONE.

Shell sand has accumulated in large quantities on the coast between John o' Groat's and the Bay of Sannick. It is burnt for lime locally. The sand probably contains a small proportion of phosphates, and has been used for lime manuring.

Deposits of lake marl are widely distributed in the flagstone area of Caithness. The marl often contains numbers of the shells of *Limnæa* and *Pisidium*. A good section of marl underlying peat is exposed in the drained Loch Brickigoe near Yarrows. An analysis of this marl shows *—

	per cent.			
Carbonate of Lime	..	..	..	75
Alumina	..	..	..	8
Silica	..	..	..	5
Organic matter	..	..	..	12

Marl from the lochs was formerly much used for agricultural purposes. It has been obtained by dredging from Loch Watten, Loch Calder, and Loch Stemster, and by lowering the water at Loch Watanan. It was also obtained from Lochs Duran, Leurary, Westfield, Alterwall, and Brickigoe, which have been drained. It is probable that most of the lochs in the flagstone area contain marl.

Marl has also been obtained beneath the peat at Dounreay, Stanstill, Bilbster, and elsewhere. Small deposits of calcareous tufa are formed by springs in the bogs at Mey and near Freswick, and have been locally used.

Beds of limestone of considerable purity are widely distributed in Caithness. A tufaceous limestone about 12 ft. thick was formerly quarried about 1 mile south of Achvarasdal in the Reay district. It was burnt for lime in kilns near the quarries.

A limestone of similar character is exposed on the cliff top at Red Point, west of Reay. Its thickness varies between 12 and 4 ft. within a short distance, and it is not likely that these limestones have more than a very local development. It is otherwise, however, with good limestones at Papigoe, Port of Brims, and Forse, near Lybster. These remain of constant thickness, interbedded in the flagstones, and may have a wide distribution.

* We are indebted to Mr. Simpson of Wick for a copy of this analysis.

The limestone at the Port of Brims is 4 ft. thick, and has been worked for lime. The Forse limestone is exposed on the coast at Robbery Head, south of Lybster. It strongly resembles the last, and is 6 ft. thick or more.

There are also many limestones in the Wick and Helman Head groups in the lower part of the Flagstone Series. They are not so pure as the above, but are often 4 ft. or more in thickness. They are exposed on the coast at Wick, Lybster, Clyth, and Helman Head, and the same limestones outcrop inland near Ulbster, Latheron, and Dunbeath. Limestones are wanting south of Dunbeath, and considerable quantities of limestone have been lately shipped to Dunbeath from Durham.

BITUMINOUS SHALE.

A hard, black, bituminous shale, locally known as "black man," occurs in bands on the coast at Barrogill, Ackergill, Keiss, and Freswick, and has also been quarried inland at Killimster. Its appearance is suggestive of the curly oil-shales of Midlothian, but it is much harder.

MINERAL VEINS.

Most of the crushes and joints in the flagstones are sealed by calcite, but locally barytes occurs and sometimes small quantities of galena, copper pyrites, and fluorspar.

A large vein of barytes is exposed on the coast in Ray Goe, near Clythshore, where it occupies a crush in the rocks. A width of over 6 ft. and a depth of 20 ft. of rather pure barytes is seen, and the vein probably has greater extension beneath the debris backing the goe.

Small pieces of a brown mineral are included in the vein. The vein has only been followed a short distance inland.

An analysis of this vein by Mr. Coghill of Liverpool in 1903 is appended below:—

Sulphate of barium	..	..	..	85.20
" alumina	..	..	..	.45
" lime ..	..	..	..	.48
" soda ..	..	..	..	.93
" magnesia	..	..	..	.60
Silica	..	..	..	11.00
Undecomposed by fusion	..	..	..	.50

99.16

A smaller exposure of barytes is seen inland, near Warehouse, in the Glamor north of Bruan.

No galena has been detected in these veins, but it occurs in small quantities in company with copper pyrites at North Head, Wick, at Staxigoe, and a few other places along the coast. It has never been found in sufficient quantity to repay working. A richer vein of galena has lately been reported from Spital, January 1912.

A vein of copper ore is said to have been worked on the coast south of the Old Castle of Wick in the fifteenth century. Fluorspar in small crystals occurs in veins in joints at Scholl, near Noss Head.

Iron and Manganese Ores.—Large masses of spongy bog iron ore are found beneath the peat between Brabstermire and Gills and also at Dunnet Head, but such deposits are not common in Caithness.

Manganese ore was found near Loch nan Clach Geala, five miles south of Reay.* A spring rising in the midst of the peat bogs north-west of Freswick deposits quantities of manganese mud. The manganese deposit, of which the analysis is given below, is found in considerable quantity as a blue-black mud where the spring issues. The spring is a source of one of the small feeders of the Burn of Bog, a northern branch of the Gills Burn. It is situated about 100 yds. from the main stream, and at a distance of about 1660 yds. in a north-west direction from the Bridge of Freswick. The water of the spring is clear and smells strongly of sulphuretted hydrogen. The spring has long been known to the local geologists as a source of sulphuretted hydrogen and manganese mud, and was explored by the writer and Mr. John Nicholson of Nybster on more than one occasion to obtain material for analysis.

Analysis (by W. Pollard, M.A., D.Sc., and E. G. Radley):—

SiO ₂	..	..	..	..	..	33
(FeAl) ₂ O ₃	..	..	..	..	..	23
MnO	..	..	..	..	..	56.07
(CoNi)O	..	..	..	..	..	10
BaO	..	..	..	..	..	1.26
CaO	..	..	..	..	..	70
MgO	..	..	..	..	..	15
K ₂ O	..	..	..	..	..	33
Na ₂ O	..	..	..	..	..	13
P ₂ O ₅	..	..	..	..	..	05
SO ₃	..	..	..	..	..	16
Loss on ignition	..	..	..	..	..	36.55
Peroxide O equivalent to MnO (i.e. in ratio						
3 MnO : O = Mn ₃ O ₄ Calc.)						
						4.21
						100.27 †

PEAT.

Peat is the chief fuel in Caithness, but has been superseded by coal in Wick and Thurso. There appear to be several kinds of peat of very different value from the economic standpoint. Peat formed in well-drained positions on slopes is generally thin and difficult to cut. Much of the high-level plateau peat is formed so largely of mosses that it falls into a powdery mass when dry, and would need special treatment if used for economic purposes. The best peat seems to be that formed by a mixture of mosses and sedges on the margins of the larger peat mosses, on old alluvial terraces and in the smaller hollows. There is a large area of peat in the county, but much of it would probably be unavailable as fuel by the ordinary process of cutting and drying. Stumps of pines buried in the peat are widely distributed in the central parts of the county and are locally used for firewood.

WATER SUPPLY.

The water supply of Caithness is essentially a surface supply. The purest supply is that obtained from springs on the flanks of Scaraben, which is brought in pipes to Berriedale.

By far the largest supply is derived from the peat. Though pure

* *New Statistical Account*, 1895, vol. xv. (Caithness), p. 15.

† "Summary of Progress for 1909," *Mem. Geol. Surv.*, 1910, p. 73.

in other ways it is liable to be much contaminated at its source by peaty matters, but fortunately many of the lakes contain sufficient lime in their incoming waters to cause a purification by precipitating the soluble humus derivatives. These lakes act as natural filters and settling tanks. Over much of the countryside water is still obtained from shallow wells, and is therefore liable to pollution. The following accounts of the water supply of Wick and Thurso have been kindly supplied by Mr. Simpson of Wick and Mr. Durran of Thurso :—

“The Royal Burgh of Wick has an abundant and wholesome water supply from the Loch of Yarrows, which is distant to the south about seven miles. The area of the loch is 104 acres, and the catchment about 16,000 acres.

“The loch is situated among a range of pasture- and moor-clad hills, 302 ft. above sea-level. A covered filter-bed, and a settling-tank capable of containing 100,000 gallons of water, are situated at Toftcarl, about half-way to the town, 200 ft. above the sea. The supply can be either taken from the loch direct or from the tank as desired. The works were opened by Mrs. Dunbar of Hempriggs in the year 1882; the scheme cost £7000. In 1905 the system of water supply was increased to meet the wants of the extended Burgh of Wick and Pulteneytown, the iron piping was doubled, and another settling tank at Toftcarl was made capable of holding 200,000 gallons. The additional supply was completed at a cost of £12,000. The shipping at the Port of Wick is supplied by arrangement between the Harbour Trust and the Town Council. Wick is a very ancient town, and before the Yarrows water was introduced the supply was got from dug wells, as is customary in most towns and country districts. The buckets were often dipped into the fountains; in more recent times the wells had pumps attached, and the water was distributed in a more cleanly fashion. Pulteneytown, before the amalgamation, had its water supply from Loch Hempriggs, situated about two miles southward; it was brought into the town by an open viaduct. The right to the water from Hempriggs Loch is still retained by the extended burgh.”

“For very many years the inhabitants of the ancient Burgh of Thurso depended mainly for their water supply on the ‘old pump well,’ which is still preserved as one of the old landmarks. Situated near the centre of the town, this well, fed by a good spring, delivered a supply which probably met the then requirements of the burgh. A very modest but continuous source of income was earned by women who used to carry the water to dwelling-houses, at so much per bucket, with the news of the day thrown in for discount.

“Doubtless on account of more modern views prevailing as regards sanitation and public health, the Local Authority in 1872 arranged for a gravitation water supply from the Loch of Calder, situated over seven miles from the town.

“The new water scheme cost £11,000, which was met by a loan spread over fifty years. But while Thurso has an ample source for its water (the loch being a very large one), the supply for the town is only moderate, has to be carefully watched, and the waste checked. From the reservoir, which is situated towards the west of the town, to the loch the rise is only 42 ft., which, spread over seven miles, gives a very moderate head of pressure.

“Again, on grounds of economy no doubt, the Local Authority only

laid down a 6-in. diameter pipe, which has had in past years to be scraped, with doubtful results.

"Some years ago the Town Council had the site surveyed for the purpose of laying down a second pipe. They were met, however, with considerable difficulties, in the way of increased water rents and charges, which assumed such proportions that the scheme was dropped and the attention of the Council devoted towards a new sewage system. The quality of the water from the loch is good, and at present it looks as if the townspeople will have to be content with their present supply for some years to come."

FORESTRY.

It may seem out of place to speak of forestry in Caithness, but trees are not quite so scarce as is generally imagined. It is true that trees only grow well when protected from the fierce gales which sweep the county from sea to sea. The most dangerous desiccating wind blows from the north-north-west in the cold of winter-time, but the onshore winds at all times also produce a marked stunting effect on the growth of trees. Natural protection from the wind is only found along the deeply sunken river-channels, and especially those that flow eastward into the North Sea. Thus the only extensive natural woods occupy protected places along the Langwell, Berriedale, and Dunbeath Waters.

Plantations have done fairly well in places on the surface of the plateau and plain of Caithness, but the trees are dwarfed. The average height of the trees would doubtless be considerably increased were they planted on a greater scale for self-protection, as they are always more stunted towards the margins of such plantations.

The indigenous trees in Caithness are the birch, hazel, aspen, rowan, alder, bird-cherry, and willow. There are a few small pines growing on Creag Sgorach, by the Langwell Water, but these are probably self-sown from the trees of the plantations. From the evidence of the buried forests in the peat, the Scots pine has, however, flourished in a past epoch of the post-glacial history of the county, but long ago became extinct. It is improbable that man had any influence in the disappearance of the pine from Caithness, but there is little doubt that hazel, birch, alder, and willow have had their distribution considerably curtailed by his interference. According to all who have had means of observation, the birch woods are sensibly dwindling, and a few stunted hazels alone remain on craggy places which formerly supported thick scrub. Many bogs named in Gaelic after the alder and willow now support no trees. The older editions of the 6-in. ordnance maps show trees along some watercourses where they are absent now or greatly reduced in numbers. The principal causes responsible for this change are no doubt the destruction of the seedlings, and in some cases the barking and stripping of the older trees by rabbits, sheep, and deer, and, further, the reckless manner in which the heather-burning is prosecuted. Sheep may still be seen continuing in this work of destruction in the Dunbeath strath, and the results of the free roaming of deer and incursions of rabbits in the Langwell plantations are only too well known to the owners and keepers. To the natural woods of these districts there has been added recently

an even worse enemy in the form of a caterpillar pest which completely strips the birch trees of their leaves. Year by year the devastation continues, until, it is feared, the straths will be robbed completely of their woodland beauty. In many places few of the trees have escaped death from this caterpillar plague, and it becomes a serious question how restoration of the birch woods can be effected.*

The reasons for the seedling birch failing to grow beneath the parent trees is not clear. It does not seem to be merely a matter of light or warmth. Rowan seedlings are abundant in the birch woods, and are prevented from growing up by the deer. One very noticeable difference between the seedling birch and rowan is the much shorter radicle of the first named in proportion to the shoot. The Caithness birchwoods usually have the ground densely covered by moss cushions, and the thickness of these cushions may, perhaps, prevent the short-rooted birch seedling from developing.

From the point of view of reforestation with birch, it is, however, evident that young heather forms a natural nursery for the birch seedlings, and wherever a new growth of birch is required it is of first importance to protect the heather strips in and surrounding birch-woods from firing and from the inroads of deer.

The Langwell plantations, the best in Caithness, have an area of nearly 200 acres. The full list of the planted trees at Langwell is as follows † :—

Lime, sycamore, hawthorn, whitebeam, elder, ash, sea buckthorn, mountain elm, beech, oak, horse-chestnut, laburnum, Scots pine, larch, spruce, yew; also, *Taxus baccata* var. *fastigiata*, *Pseudotsuga Douglasii*, *Picea Parryana*, *Araucaria imbricata*, *Cedrus Deodara*, *Cupressus Lawsoniana*, *C. argentea*, *C. lutea*, *Abies cephalonica*, *A. nobilis*, *A. Nordmanniana*, *Pinus Laricio*, *P. austriaca*, *P. strobus*, *Retinospora pissifera*, *Thuja Lobbii*, *Sequoia gigantea*. The Sequoias and araucarias were planted in 1857. Two of the former, cut down in 1907, measured over 36 ins. in diameter; one araucaria, cut down at the same time, 18 ins. The araucarias have kept their branches green down to the ground.

The largest timber other than the conifers consists of ash, mountain elm, beech, and sycamore, and is supposed to have been planted about the year 1800. Four of the latter, near the Langwell gardens, measure over 10 ft. in girth, and have fairly straight boles at least 30 ft. in length. Many of the other trees are of nearly the same proportions. Trees which have been blown down have furnished good timber. The next planting, about the year 1830, of Scots pine, is now approaching maturity. Another planting occurred about the year 1860, after the late Duke of Portland acquired the land. These include the Scots pine, spruce, larch, elm, ash, and sycamore, but through inattention to thinning they are not so fine as they might have been. The enclosed plantation was made twenty-three years ago, and is mostly spruce and larch with a few hardwoods and most of the ornamental conifers. They are doing well. Some of the Douglas firs are over 40 ft. in height and from 12 ins. to 15 ins. in

* C. B. Crampton, "The Vegetation of Caithness considered in Relation to the Geology," 1911, pp. 100, 126.

† Mr. King, the factor, and Mr. William Macpherson, the head gardener at Langwell, supplied most of the above information.

diameter. The next planting was in 1892, with about 20 acres of larch. The trees have done remarkably well and are free from disease. The latest planting round the factor's house of pine and larch is doing well, the leaders of the larch attaining 36 ins., and of the pine 22 ins.

There are many other smaller plantations in Caithness at Dunbeath, Lybster, Forse, Latheronwheel, Camster, Thrumster, Hempriggs, Stirkoke, Barrock House, Stemster, Miltonpark, Thurso, Castletown, Braal, Olig, Barrogill, Reay, and Shurrery. Those near Dunbeath Castle are about 20 acres in extent and stand on the surface of the plateau near the sea. The trees are sycamore, ash, beech, alder, birch, hazel, larch, pine, poplar, whitebeam, laburnum, lime, horse-chestnut, and various species of willows. The trees are thickly planted and are about 20 ft. in height.

AGRICULTURE.

There are good descriptions of the agriculture of Caithness in the *Statistical Accounts*, and detailed accounts in the *Highland and Agricultural Society's Reports*. The following brief notes are compiled from those made during the survey of the county, and from verbal and written information kindly supplied by Mr. Sutherland of Gersa, Mr. King of Langwell, and others.

The official returns for 1912 show the following :—

Arable land, 81,862 acres,

Permanent grass, 29,518 acres,

as against a total for the county of 438,833 acres, excluding foreshore and water.

The arable land and grass land include the greater part of the parishes of Thurso, Bower, and Olig, and a more or less interrupted coastal strip from Reay to Berriedale. The arable land is based chiefly on drift or peat, while the permanent grass lands comprise the alluvial stretches, the maritime pastures, and parts of the reclaimed moorland that have proved unprofitable or inconvenient for tillage.

By far the greater part of the arable land falls within the area of distribution of the calcareous shelly boulder-clay, and contrasts favourably with that on the loose, gravelly drifts in the neighbouring parts of Sutherland. In most parts of the county where the arable land is on boulder-clay, the ground slopes more or less, facilitating drainage, but stone drains are used where necessary, and of late tiles for drains have been imported from Brora. The boulder-clay soil is rather stiff for ploughing, requiring two horses and sometimes more. Much of the cultivated ground is on land from which the peat was removed by digging, but some of the fields overlie thick peat drained by deep ditches. The crops in such places are often good, and from the appearance of the surface, induced by frequent tilling and manuring, the thickness of the underlying peat would never be suspected. Where the peat was originally thin, the rapidity with which liming, aeration through cultivation, and bacterial inoculation through manuring, cause the disappearance of humus, is often very striking. Under these conditions many acres of shallow peat have disappeared, leaving hardly a trace of their former presence. Peat and cultivated land may often be seen side by side interlocked by

rectangular and entirely artificial boundaries. The reclamation of moorland in Caithness has been favoured locally by the calcareous nature of the rocks and drift and consequent large amount of lime in the surface waters. Owing to deficiency of lime in the waters and the highly permeable condition of the sandy drift forming the surface in the interior of the county, much difficulty would, however, be encountered in attempting the reclamation of the great stretches of thick peat.

Apart from the advantages of position relative to carting, etc., the depth and the nature of the peat and subsoil and the physiography of the surface appear to have been the chief factors which have influenced the reclamation of moorland.

A subsoil of calcareous boulder-clay offers great advantages over one of permeable sandy drift, and most attempts at moorland reclamation of deep peat overlying the latter have proved useless. Three very distinct conditions in deep peat need consideration from their probable effects on reclamation.

1. Over considerable areas the peat overlying both shelly boulder-clay and sandy drift is unbroken, and the lower layers are very compressed and quite dry.

2. Where the peat overlying the sandy drift has cracked and slipped, much of the surface water finds its way beneath to form a sub-peat drainage. The underlying drift is intensely leached by the acid waters, and the lower layers of the peat may be sodden.

3. Deep peat lying in hollows of the calcareous shelly boulder-clay or flagstones may be moist throughout, and the lower layers very dark, almost black. Without attempting to discuss the reasons which may have led to these differences, it is sufficient to note that a black peat, moist throughout, is the only kind which is likely to yield good results for reclamation, so far as cultivation of deep peat is concerned. The deep peat most favourable for cultivation is that lying in hollows of a calcareous boulder-clay or flagstone district. In such cases the lower layers are generally moist and dark in colour, and even where the present surface is covered by heather or other moorland plants, the lower layers were probably largely formed of fenland, marsh, or calcareous bog vegetation influenced by a periodical or constant supply of ground waters rich in lime. These deep black peats are well-supplied with waters draining the neighbouring higher ground and preventing the lower layers from drying. Some are based on calcareous marls, and evidently occupy the sites of lochans which have been filled up by the growth of fen vegetation, while others perhaps represent parts of the moorland liable to frequent flushing by calcareous waters at no time held up to form a lake. In all cases, however, the dark colour and complete saturation of the peat are perhaps the best guide to the prospects of fertility on cultivation. Cultivation over layers of dry peat must be disastrous, owing to the broken water-column between the surface and ground waters preventing the ascent of water by capillarity. Where deep peat overlies a leached permeable subsoil, cultivation also appears hopeless, but where the subsoil is calcareous boulder-clay, the prospects of reclamation depend much on the slope of the ground allowing a permanent restoration of the water-column in the peat, and providing ground waters of a sufficiently alkaline character.

In all cases the presence of lime is absolutely essential for neutralising the natural acidity of the moorland peat, and for promoting the bacterial processes necessary for cultivation.

Where the peat is thin and the surface naturally drained, even the calcareous shelly boulder-clay underlying it is liable to have been leached of its lime, and trenching may be needed to obtain sufficient lime if the latter be not artificially added as manure. In such sloping positions the moorland is, however, often naturally flushed over limited but changing areas by surface waters containing more or less lime and other salts in solution, coming from natural springs liable to overflow in wet weather or merely the outcome of surface run-off. These flushed areas never support heather, and show up plainly on the dark heathery slopes as streaks or wider splashes of a green colour due to the growth of rushes, sedges, and grasses. They are also often conspicuous at the points of overflow of the artificial drains in moorland used as sheep ground. The greater growth of grasses at these places is undoubtedly due to the neutralisation of the surface acidity of the peat by substances brought in solution or suspension in the surface waters. The superior aeration and surface warmth induced by the periodic drying are probably also of value in improving the type of pasturage. There is a natural tendency for these "flushes" to gradually migrate from one point to another on the slopes.

Old tilled patches, now grassland, may often be seen on the sites of these flushes, but it is doubtful if they would be much use for cultivation since their fertility is probably closely confined to the superficial layers of the soil, and the areas they occupy are very limited; but in adding to the value of moorland for pasturage they probably rank high.

It is possible that something might be done to improve the moorland pastures by a judicious planning of drains from springs or leaders from burns (especially where the waters contain abundance of lime in solution), such as would temporarily flush certain sections of the slopes and induce a growth of grassland which might thus be made to alternate with heather as an artificial rotation.

Lime was formerly in great demand for reclaiming peaty ground, and was obtained by calcining the limestones locally quarried for the purpose, and marl obtained by draining or dredging the lochs was also used. At the present time limestone is occasionally imported from Durham to Dunbeath, and is distributed in the district between Latheron and Berriedale, but owing to the present high price of imported lime, basic slag is much used throughout the county, and answers the double purpose of supplying lime and phosphates.

The chief crops in Caithness are oats, bere, and turnips, which are grown in rotation with grass. In the south of Caithness rye grass and clover are the chief seeds, but various others are used. Potatoes are grown in considerable quantities in Caithness and a small proportion of peas, beans, and vetches. The usual rotation in Caithness is oats, turnips, oats, seeds, and grass. Extensive permanent pastures are found on sandy alluvia in the Langwell forest. Here the chief grasses are sheep's fescue, white bent, sweet vernal, with white clover. The fine large pasture near Langwell House has been permanent for seventy years, and lies on sandy boulder-clay. It is dressed periodically in sections with lime, kainite, and basic slag.

In the region of the shelly boulder-clay the wide alluvial loams of the Thurso and Wick Rivers are subject to flooding, and are used as grazing for cattle. The chief grasses are white bent, dogstail, cocksfoot, smooth and rough stalked meadow grass, but the pasture is rough and contains much tussock grass, rushes, and sedges. The grassland of the alluvial terraces along the Achairn Burn, Strath Burn, Burn of Acharole, Strathmore and Glutt Waters, like those of Langwell, are rarely flooded and form pastures for sheep. A prominent type of sheep pasture in Caithness is the down-like sward along the cliff top. It usually contains much *Festuca ovina* (sheep's fescue), *Festuca rubra*, *Koeleria cristata*, *Agrostis alba* (white bent), *Triodia decumbens*, and small sedges and sward-forming halophytes. The thin grass on the links behind the sand-dunes at Reiss and Dunnet is also grazed by sheep, which appear to relish greatly the flowering tops of *Carex arenaria* and *Juncus balticus*, and will probably in time lead to the extermination of the latter plant.

C. B. C.

APPENDIX.

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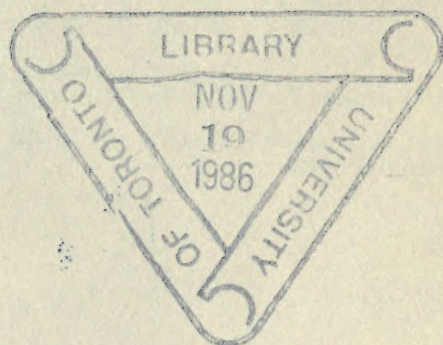
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